# DEVELOPMENT OF DECISION SUPPORT SYSTEMS TOWARDS SUPPLY CHAIN PERFORMANCE APPRAISEMENT

**A Dissertation Submitted in Fulfillment of the Requirement for the Award of the Degree of**

## Master of Technology (By Research)

**IN**

## MECHANICAL ENGINEERING

## (Production Engineering Specialization)

**BY**


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# CERTIFICATE OF APPROVAL

Certified that the dissertation entitled **DEVELOPMENT OF DECISION SUPPORT SYSTEMS TOWARDS SUPPLY CHAIN PERFORMANCE APPRAISEMENT** submitted by **Santosh Kumar Sahu** has been carried out under our supervision in fulfillment of the requirement for the award of the degree of ***Master of Technology (By Research)*** in ***Mechanical Engineering (Production Engineering Specialization)*** at **National Institute of Technology**, **Rourkela** and this work has not been submitted to any university/institute anywhere before for any other academic degree/diploma.

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# Abstract

**Purpose:** The aim of this research is to develop various Decision Support Systems (DSS) towards supply chain (SC) performance appraisement as well as benchmarking. The purpose of this work is to understand multi-level (measures and metrics) performance appraisement index system to evaluate overall supply chain performance extent, monitor ongoing performance level and to identify ill-performing areas of the supply chain network.

**Design/methodology/approach:** Fuzzy logic as well as grey theory has been explored in developing a variety of SC performance appraisement modules (evaluation index systems). Generalized fuzzy numbers, generalized interval-valued fuzzy numbers theory have been utilized in order to tackle decision-makers' linguistic evaluation information towards meaningful and logical interpretation of procedural hierarchy embedded to the said appraisement modules. Fuzzy-grey relation theory, MULTIMOORA method coupled with fuzzy logic as well as grey theory have also been adapted to facilitate overall SC performance assessment, performance benchmarking and related decision making.

**Findings:** Supply chain performance index has been computed in terms of fuzzy as well as grey context, suggesting the present performance status of the said organizational supply chain. Ill-performing areas of the SC have been identified too. Fuzzy as well as grey based MULTIMOORA (MOORA: Multi-Objective Optimization by Ratio Analysis), fuzzy-grey relation analysis, thus adapted, appeared helpful in evaluating performance ranking order (and selecting the best) of various candidate alternatives (industries/enterprises) operating under similar supply chain architecture according to the ongoing SC performance. Empirical illustrations exhibited the fruitful application potential of the developed decision support tools.

**Practical implications:** The decision support tools thus proposed may be proved fruitful for companies that are trying to identify key business performance measures for their supply chains. Ill-performing areas can easily be identified; companies can seek for possible means in order to improve those SC aspects so as to improve/enhance overall SC performance extent. Benchmarking may help in identifying best practices in relation to the SC which is performing as ideal (benchmarked practices). Best practices of the ideal organization need to be transmitted to the others. Companies can follow their peers in order to improve overall performance level of the entire supply chain. In view of this, the work reported in this dissertation may be proved as a good contributor for effective management of organizational SC.

**Research limitations:** The methodology and presentation is conceptual, yet the tool can provide very useful interpretations for both researchers as well as management practitioners. Accessibility and availability of data are the main limitations affecting which model will be applied. Procedural steps towards implementing the said decision support tools have been demonstrated through empirical research. The decision support tools tools have neither been validated by practical case study nor have these been tested for assessing their reliability.

**Originality/value:** This work articulates various approaches for supply chain performance evaluation considering multiple evaluation criteria (subjective evaluation indices), with a flexibility to modify and analyze using the available data sets collected from a group of experts (decision-makers). The approaches of performance evaluation index system are attempted due to structure and fuzzy (as well as grey) sets. The work is aimed at operational researchers, engineers and special managers.

**Keywords:** Decision Support Systems (DSS); supply chain (SC) performance appraisement; benchmarking; Fuzzy logic; grey theory; Fuzzy-grey relation theory; MOORA: Multi-Objective Optimization by Ratio Analysis

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# CHAPTER 1

## Background and Rationale

## 1.1 Supply Chain Performance Assessment: An Overview

Supply chain management (SCM) is a novel management concept and enterprise operation mode, and is increasingly attracting more attentions around the globe. It is predicted that the enterprise competition is nothing but due to supply chain (SC) competition in the future (Ma, 2005).

A supply chain can be considered as an integrated process wherein raw materials are manufactured and transformed into final products, then delivered/distributed to the consumers (via distribution, retail, or both) (Steven, 1989). A typical supply chain generally contains four echelons (supply, manufacturing, distribution, and consumers), where each level (or echelon) of the chain may comprise numerous facilities. Thus, the complexity of the supply chain arises from the number of echelons in the chain and the number of facilities in each echelon (Beamon, 1999). Firms are adopting supply chain management (SCM) in view of reducing costs, increasing market share and sales, and maintaining solid customer relations (Ferguson, 2000).

The subject of supply chain management was already investigated by the pioneers and reported in the literature. While there are many ongoing research efforts on various aspects of SCM, so far little attention was given to the performance evaluation, and hence, to the measures and metrics of supply chains. A notable work in this area was performed by Stewart (1995). New (1996) used taxonomy to discuss a framework for improving supply chain performance. As a pitfall in managing supply chain inventories, Lee and Billington (1992) also drew attention to the lack of supply chain metrics.

SCM can be viewed as a philosophy based on faith that each firm/enterprise in the supply chain directly and indirectly affects the performance of all the other supply chain members, as well as ultimately, overall supply chain performance extent (Cooper et al., 1997). The effective utilization of this philosophy requires that functional and supply chain partner activities need to be aligned with company strategy and harmonized with organizational structure, processes, culture, incentives and people (Abell, 1999). Additionally, the chain wide deployment of SCM practices consistent with the aforementioned philosophy is needed to provide maximum benefit to its members (Lockamy III and McCormack, 2004).

In recent years, a number of firms have realized potential benefits of adapting supply chain management in day-to-day operations management. However, they often lack the insight for the development of effective performance measures and metrics required to achieve a fully integrated SCM due to lack of a balanced approach and lack of clear distinction between metrics at strategic, tactical, as well as operational levels (Gunasekaran et al., 2001; Hudson et al., 2001). Therefore, it is clear that for effective SCM, measurement goals must consider the overall scenario and the metrics to be explored (Kaplan and Norton, 1997). These should represent a balanced approach and should be classified at strategic, tactical, and operational levels, and include financial as well as non-financial measures of supply chain performance extent (Sharma and Bhagwat, 2007).

The need for performance measurement systems at various levels of decision making, either in the industry or in the service sectors (contexts), is undoubtedly not something new (Bititici et al., 2005; Bagchi, 1996). Gunasekaran et al. (2001, 2004) claimed the existence of a greater need towards studying different measures and metrics in the context of SCM for two reasons: (a) Lack of a balanced approach; and (b) Lack of clear distinction between metrics at strategic, tactical, and operational levels.

During the past decade, a number of supply chain research topics and methodologies were articulated (Tayur et al., 1998). Optimization criteria in supply chain models were included cost (Camm et al., 1997), inventory levels (Altiok and Ranjan, 1995), profit (Cohen and Lee, 1989), fill rate (Lee and Billington, 1993), stock out probability (Ishii et al., 1988), product demand variance (Newhart et al., 1993), and system capacity (Voudouris, 1996). Most deterministic and stochastic models dealt with isolated parts of the supply chain system such as supply-production, production-distribution, or inventory-distribution systems. Some models were emphasized with strategic issues for supply chains such as the most cost-effective location of plants and warehouses, flow of goods, etc., while others were concerned with operational issues such as order size, fill rate, inventory levels, etc. However, measuring supply chain performance must be considered as an important source of competitive information (Liang et al., 2006).

Given the inherent complexity of the typical supply chain, selecting appropriate performance measures for supply chain analysis is indeed particularly critical, since the system of interest is generally large and complex.

Performance improvement at an individual supply chain echelon does not lead to improvement in the supply chain as a whole. To measure the supply chain performance effectively, it is necessary to consider the complex multilayered internal linking activities between multiple entities (Tavana et al., 2013). In order to analyze the efficiency and benefits of SC scientifically and objectively, the performance evaluation system and method of SC should be established accordingly (Ma, 2005).

## 1.2 Understanding of State of Art

'Measurements are the key. If you cannot measure it, you cannot control it. If you cannot control it, you cannot manage it. If you cannot manage it, you cannot improve it' (Harrington 1991). The concept of performance measurement is progressing and in recent years, many research studies have been done regarding the nature and the methodologies of measuring performance in organizations. A very valuable point in the supply chain environment for organizations is that they know where they are now, how they got here and what the future will be (Morgan 2004). Performance measurement systems have been on the top of business research list which are being performed during the recent years. Business companies realized the importance of the balanced performance measurement system as a tool to promote the organization (Najmi and Makui, 2012).

Effective management of an organization's supply chains has proven to be a very effective mechanism for providing prompt and reliable delivery of high-quality products and services at the least cost. To achieve this, performance evaluation of the entire supply chain is extremely important. This means utilizing the combined resources of the supply chain members in the most efficient way possible to provide competitive and cost-effective products and services. However, lack of appropriate performance measurement systems has been a major obstacle to effective management of supply chains (Lee and Billington, 1992).

A performance measurement system plays an important role in managing a business as it provides the information necessary for decision-making and actions (Gunasekaran and Kobu, 2007). As per Kaplan (1990), ''No measures, no improvement,'' it is essential to measure the right things at the right time in a supply chain so that timely action can be taken. Performance measures and metrics are not just measuring the performance. They are also embedded with politics, emotions and several other behavioral issues. Good performance measures and metrics will facilitate a more open and transparent communication between people leading to a co-operative supported work and hence improved organizational performance.

The purpose of measuring organizational performance is to (a) identify success; (b) identify whether customer needs are met; (c) help the organization to understand its processes and to confirm what they know or reveal what they do not know; (d) identify where problems, bottlenecks, waste, etc. exist and where improvements are necessary; (e) ensure decisions are based on facts, not on supposition, emotion, faith or intuition; and (f) show if improvements planned actually happened (Parker 2000). Traditional business performance measures have been mostly financial – measuring rate of return on investment, cash flow and profit margins.

However, conventional measures have the drawbacks of tending toward inward looking; fail to include intangibles and lagging indicators. This forced researchers and companies to revisit the performance measures and metrics in the new economic environment (Parker 2000).

Neely et al. (1995) defined performance measurement as the process of quantifying the effectiveness and efficiency of an action. Effectiveness is the extent to which a customer's requirements are fulfilled and efficiency measures how economically a firm's resources are being utilized when providing a pre-specified level of customer satisfaction. Performance measurement systems can be described as the overall set of metrics used to quantify both the efficiency and effectiveness of action. In the same paper, Neely et al. (1995) identified a number of approaches to performance measurement, including: the balanced scorecard (Kaplan and Norton, 1992); the performance measurement matrix (Keegan et al., 1989); performance measurement questionnaires (Dixon et al., 1990); criteria for measurement system design (Globerson, 1985); and, computer aided manufacturing approaches. Moreover, they highlighted a range of limitations of existing measurement systems for manufacturing, including: they encourage short termism; they lack strategic focus (the measurement system is not aligned correctly with strategic goals, organization culture or reward systems); they encourage local optimization by forcing managers to minimize the variances from standard, rather than seek to improve continually; and, they fail to provide adequate information on what competitors are doing through benchmarking (Shepherd and Günter, 2006).

Beamon (1999) presented a framework for the selection of performance measurement systems for manufacturing supply chains. Different dimensions for flexibility measures in supply chains were developed. Gunasekaran et al. (2001) developed a framework for measuring the strategic, tactical and operational level performance in a supply chain. The emphasis was on performance measures dealing with suppliers, delivery performance, customer-service, and inventory and logistics costs in a SCM. In developing the metrics, an effort was made to align and relate them to customer satisfaction. Chan and Qi (2003a) proposed a process-based approach towards mapping and analyzing the practically complex supply chain network. A processed-based performance measure system was proposed, in which a method called performance of activity was used to identify the performance measure and matrices. In another paper, (Chan and Qi, 2003b) attempted to propose an innovative performance measurement method to contribute to the development of supply chain management. A process-based systematic prospective was employed to build an effective model to measure the holistic performance of complex supply chains. Fuzzy set theory was introduced to address the real situation in judgment and evaluation processes. Gunasekaran et al. (2004) developed a framework to promote a better understanding of the importance of SCM performance measurement and metrics. Using existing literature and the results of an empirical study of selected British companies, the authors developed the framework that stimulated more interest in this important area.

Chen and Paulraj (2004) developed a research framework that improved understanding of SCM; stimulated and facilitated the researchers to undertake both theoretical and empirical investigation on the critical constructs of SCM, and the exploration of their impacts on supply chain performance. The authors analyzed over 400 articles and synthesized the large, fragmented body of work dispersed across many disciplines such as purchasing and supply, logistics and transportation, marketing, organizational dynamics, information management, strategic management, and operations management literature. Caputo et al. (2004) proposed a model for the analysis and performance evaluation of e-supply chains (e-SCs) (supply chains in which actors are connected by Internet technologies). It was assumed that e-SC performances are influenced by the network organizational structures, by the criteria adopted to manage relationships among involved actors, and by the critical activities that the leading company performs. The output of this model might be used to design totally new e-SCs or to redesign the existing ones, in both manufacturing and services industries. Lai et al. (2004) conducted a cross-sectional survey with firms in three transport logistics industry sectors, i.e., air and sea transport, freight forwarding, and third-party logistics services, to evaluate their perceived SCP in transport logistics from both cost and service perspectives. The study's findings provided managerial insights for the industries to understand their supply chain performance (SCP) in transport logistics and to benchmark areas to improve their performance. Lockamy and McCormack (2004) investigated the relationship between supply-chain management planning practices and supply chain performance based on the four decision areas provided in SCOR (Supply Chain Operations Reference) Model Version 4.0 (PLAN, SOURCE, MAKE, DELIVER) and nine key supply-chain management planning practices derived from supply-chain management experts and practitioners. Planning processes were found important in all SCOR supply chain planning decision areas. Collaboration was found to be most important in the Plan, Source and Make planning decision areas, while teaming was most important in supporting the Plan and Source planning decision areas. Process measures, process credibility, process integration, and information technology were found to be the most critical in supporting the deliver planning decision area.

Perona and Miragliottam (2004) investigated how complexity could affect a manufacturing company's performances, and those of its supply chain. In depth industry case studies involving 14 Italian companies at different stages in the household appliances industry were presented:

more than 200 numerical data and 50 descriptive questions were asked to eight different key managers within each company, focusing on sales, inbound and outbound logistics, product and process engineering, production and organizational issues. The model suggested that the ability to control complexity within manufacturing and logistics systems could be regarded as a core competence in order to jointly improve efficiency and effectiveness at a supply chain wide scale.

Manzini et al. (2005) dealt with five significant industrial cases, which were simulated in collaboration with important enterprises and belonged to different industrial sectors, in order to obtain an original quantitative analysis of time and costs resulting from a simulation optimization based on the introduction of a set of innovative performance indices. Discrete/continuous hybrid simulation tools were used in order to model and simulate several operating conditions in combination with different system configurations. The case studies showed the importance of simulation in supporting decisions concerning the design and management of supply chains in their great complexity and in a stochastic competitive and extended context.

Shepherd and Gunter (2006) provided taxonomy of performance measures followed by a critical evaluation of measurement systems designed to evaluate the performance of supply chains. The authors stressed on the factors influencing the successful implementation of performance measurement systems for supply chains; the forces shaping their evolution over time; and, the problem of their ongoing maintenance. Liang et al. (2006) reported on applications of DEA models for evaluation of supply chain efficiency. Bartlett et al. (2007) investigated the links between different types of visibility, joint initiatives and business performance using the concepts of transparency as a measure of visibility in supply chains. The prognosis that increased supply chain visibility could be achieved through suppliers and a customer working on joint initiative(s), the deployment of which could lead to collaborative successes, was tested. The work demonstrated tangibly that the exchange of high-quality information as part of an improvement initiative does lead to significant improvements in the overall performance of the supply chain.

Sharma and Bhagwat (2007) developed an integrated balanced scorecard (BSC) analytical hierarchy process (AHP) approach for supply chain management (SCM) evaluation. This research aimed to measure SCM performance from the following four perspectives: finance, customer, internal business process, and learning and growth. Fawcett et al. (2007) provided an understanding on how information technology (IT) could be used to enhance supply chain performance. Two distinct dimensions to information sharing: connectivity and willingness were identified and analyzed. Both dimensions were found to impact operational performance and appeared to be critical to the development of a real information sharing capability. Lee et al.

(2007) presented the relationship between supply chain linkages and supply chain performance (cost-containment and reliability of supply chain partners). Multivariate regression models were developed in order to identify the characteristics of determinants of linkages in the supply chain stakeholders (suppliers, internal stakeholders and customers).

Gunasekaran and Kobu (2007) determined the key performance measures and metrics in supply chain and logistics operations by considering the importance of nonfinancial measures and intangibles. Bhagwat and Sharma (2007a) proposed the use of the analytical hierarchy process (AHP) methodology as aid in making SCM evaluation decisions. For pair-wise comparison in AHP, a survey methodology was used. The methodology presented could help firms to prioritize and formulate viable performance measurement strategies in the volatile and complex global decision environment from different balanced scorecard (BSC) perspectives. Aramyan et al. (2007) contributed to the development of a performance measuring system (PMS) for agri-food supply chain that involved the entire chain (i.e. all stages starting from raw material to retailers) and included a comprehensive set of performance indicators. The result showed that the choice of marketing channel had an impact on the performance of growers (i.e. growers who used mixed marketing channels, on average, were relatively more efficient than those who sold their total produce through auctions). The application of the conceptual framework was carried out by looking at the perceived impact of different requirement Quality Assurance system (QAS) on the performance of a Dutch tomato supply chain. Bhagwat and Sharma (2007b) developed a balanced scorecard for supply chain management (SCM) that could measure and evaluate day-to-day business operations from following four perspectives: finance, customer, internal business process, and learning and growth. The authors conducted three case studies, each illustrating ways in which BSC was developed and applied in small and medium sized enterprises (SMEs) in India. The paper further suggested that a balanced SCM scorecard could be the foundation for a strategic SCM system provided that certain development guidelines are properly followed, appropriate metrics are evaluated, and key implementation obstacles are overcome.

Thangavelu and Samavedham (2007) developed an assessment framework to examine and enhance the performance of an existing supply chain. Data from an existing network was used to determine the bottlenecks or poorly performing nodes. With the knowledge of supply chain architecture, time-series data analysis techniques were employed. Simulation based optimization were extensively employed to enrich the performance of the inferior nodes close to achievable benchmark standards by minimizing the supply chain cost. Field and Meile (2008) aimed to empirically test the relationship between supplier relations and satisfaction with overall supplier performance in a services context at a process level of analysis. Two hypotheses were developed, one predicting a positive relationship between a multi-dimensional construct of supplier relations and satisfaction with overall supplier performance, and one five-part hypothesis predicting positive relationships between the underlying components of supplier relations and satisfaction with overall supplier performance.

McCormack et al. (2008) investigated the relationship between supply chain maturity and performance, with specific references both to the business process orientation maturity model and to the supply chain operation reference model. Quantitative, survey based research was carried out with 478 Brazilian companies. Statistical analysis combined the use of descriptive statistics and structural equation modeling. Empirical results indicated a strong and positive statistical relationship between supply chain maturity and performance. The results also suggested that the deliver process maturity had a higher impact on overall performance than the other supply chain processes. Varma et al. (2008) used a combination of analytical hierarchy process (AHP) and balanced scorecard (BSC) for evaluating performance of the petroleum supply chain. The importance of four perspectives with respect to petroleum supply chain performance in descending order of importance came out as: customer, financial, internal business process, innovation and learning. Within these perspectives, the following factors seemed to be most important respectively: purity of product, market share, and steady supply of raw material and use of information technology.

Fabbe-Costes and Jahre (2008) studied the link between supply chain integration (SCI) and performance, and discussed empirical evidence relating to this fundamental question for logistics and supply chain management. Chia et al. (2009) empirically examined what senior supply chain executives' measure and how they perceive performance measurement from a balanced scorecard (BSC) perspective. Thakkar et al. (2009) proposed an integrated supply chain performance measurement framework for the case of small and medium scale enterprises (SMEs) using set of qualitative and quantitative insights gained during the case study research. This paper developed the supply chain performance measurement framework using the facts revealed through case study analysis, secondary data specific to various SME clusters in India and detailed contemporary studies reported on supply chain management in SMEs. It integrated the salient features of balanced scorecard (BSC) and supply chain operation reference (SCOR) model to deliver a comprehensive performance measurement framework for SMEs.

Chae (2009) offered a practical approach to supply chain performance measurement and to present a list of essential key performance indicators (KPIs). The experience from, and the review of, industry standards and best practices in supply chain performance measurement suggested that ‘less is better’ as to developing performance metrics. Companies should focus on only a small list of KPIs which are critical for their operations management, customer service, and financial viability. Potential KPIs should be developed for each of the supply chain operations-reference (SCOR) model’s four meta-processes (plan, source, make, and delivery) and need to be hierarchically grouped such as primary and secondary metrics. Yang (2009) analyzed the efficiency and benefits of supply chain (SC) scientifically and validated the usability of methods on performance evaluation index system. At the performance evaluation index, the enhanced balanced scorecards (BSC) were developed based on the BSC. Regarding society environment and future development, the construction of performance evaluation index system included five aspects such as finance, customer service, intra-flow process, learning and development, and society development within SC. The approach of performance evaluation index system was attempted due to structure and fuzzy sets. Hofmann and Locker (2009) investigated the development of a value-based performance measurement concept in supply chains on the basis of a case study from a packaging industry. The value-based view offered a direct link between operating supply chain activities and shareholder value creation expressed in the economic value added (EVA).

Cai et al. (2009) proposed a framework using a systematic approach towards improving the iterative key performance indicators (KPIs) accomplishment in a supply chain context. The proposed framework quantitatively analyzed the interdependent relationships among a set of KPIs. It could identify crucial KPI accomplishment costs and proposed performance improvement strategies for decision-makers in a supply chain. Tsai and Hung (2009) proposed a fuzzy goal programming (FGP) approach that integrated activity-based costing (ABC) and performance evaluation in a value-chain structure for optimal green supply chain (GSC) supplier selection and flow allocation. The FGP approach was found particularly suitable for such a decision model which included flexible goals, financial and non-financial measures, quantitative and qualitative methods, multi-layer structure, multiple criteria, multiple objectives, and multiple strategies. Kim (2010) developed a framework for assessing the comprehensive performance of supply chain partnership (SCP). The framework was based on the self-assessment dimensions and approaches of the business excellence model developed by the European Foundation for Quality Management (EFQM). The proposed framework could be implemented not only in entire supply chains, but also in a dyadic relationship.

Shaw et al. (2010) reviewed extant literature and presented a proposed research agenda to examine whether environmental, i.e. green performance measures, could be integrated within an existing supply chain performance framework, explore what a meaningful industry-recognized environmental measure should look like, and understand the direct benefits of incorporating environmental measures within a supply chain performance framework. Allesina et al. (2010) developed a quantitative measurement of complexity for a supply network based on network analysis, which is often used to study natural ecosystems, focusing in particular on the concept of entropy of information. The proposed method took a holistic point of view to tackle the problem of supply network optimization.

Akyuz and Erkan (2010) revealed that performance measurement in the new supply era is still an open area of research. Further need of research could be identified regarding framework development, empirical cross-industry research and adoption of performance measurement systems for the requirements of the new era, to include the development of partnership, collaboration, agility, flexibility, information productivity and business excellence metrics. Trkman et al. (2010) investigated the relationship between analytical capabilities in the plan, source, make and deliver area of the supply chain and its performance using information system support and business process orientation as moderators. Structural equation modeling employed a sample of 310 companies from different industries from the USA, Europe, Canada, Brazil and China. The findings suggested the existence of a statistically significant relationship between analytical capabilities and performance. The moderation effect of information systems support was found considerably stronger than the effect of business process orientation.

Shafiee and Shams-e-alam (2011) generated an approach based on rough data envelopment analysis (RDEA) for evaluating the performance of supply chain. Khilwani et al. (2011) proposed an effective modeling technique, the hybrid Petri-net, in order to efficiently handle the dynamic behavior of the supply chain. This modeling methodology embedded two enticing features, i.e. cost and batch sizes, in deterministic and stochastic Petri-net for the modeling and performance evaluation of supply chain networks. The model was subsequently used for risk management to investigate the issues of supply chain vulnerability and risk that seemed to become a major research subject in recent years. Thus, this paper presented a complete package for industrial practitioners to model, evaluate performance and manage risky events in a supply chain.

Banomyong and Supatn (2011) aimed to present a supply chain performance assessment tool that measures the performance of key supply chain activities of a firm under different performance dimensions: cost, time, and reliability. The tool was pilot-tested on 44 local SMEs. The results were then compared with existing performance benchmark as well as within the benchmarked group itself and a high performing Thai multinational company in order to see whether the developed tool could identify performance gaps in the trial group. Ip et al. (2011) proposed an integrated approach towards modeling and measuring supply chain performance and stability using system dynamics (SD) and the autoregressive integrated moving average (ARIMA). A case study from a typical semiconductor equipment manufacturing company was used to illustrate and validate the said method. Effectiveness and efficiency, with six corresponding indicators (product reliability, employee fulfillment, customer fulfillment, on-time delivery, profit growth, and working efficiency), were found to be the most significant factors in the performance of the supply chain.

Saadany et al. (2011) developed an analytical decision model to investigate the performance of a supply chain when product, process, and environmental quality characteristics were considered. El-Baz (2011) presented a fuzzy decision making approach to deal with the performance measurement in supply chain systems based on fuzzy set theory and the pair-wise comparison of Analytical Hierarchy Process (AHP). In the proposed model, various input factors were selected, and treated as a linear membership function of fuzzy type. The approach provided an effective decision tool for the performance measurement of a supply chain in manufacturing environment. Ainapur et al. (2011) presented a methodology for identification of the KPI's from the supply chain metrics suitable for foundries. Selection of the KPI's was done using Supply Chain Operations Reference (SCOR) framework. Analytical Hierarchy Process (AHP) was used for decomposing the goal into micro level for analyzing and prioritizing KPIs. In order to study the gap between as-is-state and as-to-be state, benchmarking was carried by comparing foundry industry KPIs with global best practice industry average. In course of optimizing the supply chain performance, Goal Programming function was formulated using AHP ratings and solved using WINQSB software. Theory of Constraint (TOC) management philosophy was applied for finding the constraints, on improving these constraints supply chain performance enhancement was achieved.

Chen and Yan (2011) constructed an alternative network DEA model that embodied the internal structure for supply chain performance evaluation. The authors took the perspective of organization mechanism to deal with the complex interactions in supply chain. Three different network DEA models were introduced under the concept of centralized, decentralized and mixed organization mechanisms, respectively. Efficiency analysis including the relationship between supply chain and divisions, and the relationship among the three different organization mechanisms were discussed. Bai and Sarkis (2012) introduced an innovative neighborhood rough-set approach using elements of the Supply-Chain Operations Reference model. The model might aid in determining a core set of external logistics and supply-chain performance measures to internal performance expectations and outcomes.

Najmi and Makui (2012) proposed a conceptual model for measuring supply chain (SC) performance which could be used for most organizations with the same class at various industries. Furthermore, it tried to see the key features of a performance evaluation model. The methodology which was used for solving and integrating the model was a combination of the analytical hierarchy process (AHP) and Decision Making Trial and Evaluation Laboratory (DEMATEL) methods. The DEMATEL and AHP were used for understanding the relationship between comparison metrics and integration to provide a value for performance.

Bai et al. (2012) introduced a methodology to help evaluate, select, and monitor sustainable supply chain performance measurement that could be integrated into a performance management system (PMS). Grey-based neighborhood rough set theory was used to help arrive at a core set of important business and environmental performance measures for sustainable supply chains. The supply chain operations reference (SCOR) model was used to develop both business and environmental measures for supply chain sourcing.

Estampe et al. (2013) analyzed various models [Activity-Based Costing (ABC), Framework for Logistics Research (FLR), Balanced Score Card (BSC), Supply Chain Operation Reference model (SCOR), GSCF framework, ASLOG audit, Strategic Audit Supply Chain (SASC), Global EVALOG, World Class Logistics model (WCL), AFNOR FD X50-605, SCM/SME, APICS, Efficient Customer Response (ECR), EFQM: Excellence model, Supply Chain Advisor Level Evaluation (SCALE), Strategic Profit Model (SPM)] commonly used to assess supply chains by highlighting their specific characteristics and applicability in different contexts. It also offers an analytical grid breaking these models down into different layers. This grid would help managers evolve towards a suitable model for their needs. Chen and Gong (2013) presented a method for evaluating the performance of a supply chain network. The main index was cost factors, which included four categories: production costs, disruption costs, co-ordination costs, and vulnerability costs. Numerical analysis was adopted to illustrate its efficiency and effectiveness in searching for an optimal scheme in supply chain network design.

Bhattacharya et al. (2013) attempted to delineate a green supply chain (GSC) performance measurement framework using an intra-organizational collaborative decision-making (CDM) approach. A fuzzy analytic network process (ANP)-based green-balanced scorecard (GrBSc) was used within the CDM approach to assist in arriving at a consistent, accurate and timely data flow across all cross-functional areas of a business. A green causal relationship was established and linked to the fuzzy ANP approach. The causal relationship involved organizational commitment, eco-design, GSC process, social performance and sustainable performance constructs. Sub-constructs and sub-sub-constructs were also identified and linked to the causal relationship to form a network. Vaidya and Hudnurkar (2013) proposed an approach to evaluate the performance of supply chain using multiple criteria in a case from Indian chemical company. A multi-criteria decision making tool like analytic hierarchy process was used to develop a methodology for performance evaluation.

Fattahi et al. (2013) analyzed the characteristics and performance of the meat supply chain. The authors focused on developing a model for measuring the meat supply chain's performance in the province of Isfahan, Iran. Tavana et al. (2013) proposed a network epsilon-based DEA model for supply chain performance evaluation in the semiconductor industry.

From exhaustive review of past research it appears evident that performance measurement of supply chain management (SCM) is a rapidly growing multi-criteria decision-making problem owing to the large number of factors affecting decision-making. The right choice of performance metrics and measures is critical to the success and competitiveness of the firms in the era of globalization (Bhagwat and Sharma, 2007).

Motivated by this, present study aims to contribute the extent body of knowledge (value addition to the existing research documented so far) through important insights into this challenging as well as serious topic.

## 1.3 Motivation and Objectives

Supply Chain Management (SCM) has gained immense importance in the 21st century. Because small companies like Wal–Mart, Dell, and Amazon owe their entire success to their agile and adaptive supply chain. These were small companies virtually unknown not so long ago and suddenly they became the most competitive and admired companies on the stock bourse. However, some Indian companies are moving towards making their supply chain and logistics efficient, most of them have done very little or nothing. If companies choose to compete in the global environment, they will have to look for ways to reduce expenditures of their suppliers and channel partners, logistics or distribution partners. This reduction in cost will lead the revamping of supply chains and significant investment in information technology, because information technology tools and techniques plays very important role in improving the status of the SCM (Reddy, 2012).

A supply chain is basically a set of facilities, supplies, customers, products and methods of controlling inventory, purchasing, and distribution (Altiparmak et al., 2006). It is a network of suppliers, manufacturers, and distributors through which raw materials are transformed into final products and delivered to the customers. The process of transforming raw materials into final products and delivering those products to customers is becoming increasingly complex. Supply chain performance evaluation problems are seemed inherently complicated problems with multilayered internal linking activities and multiple entities. The supply chain performance measurement that only considers the initial inputs and the final outputs is generally inadequate since it ignores the internal linking activities among the suppliers, manufacturers, distributors, and customers (Tavana et al., 2013).

Market globalization has resulted supply chain management as one of the critical issues need to be discussed. An efficient supply chain is capable of producing a range of benefits, including reduced cost, increased market share and sales, and sustainable customer relationship. Efficiency of supply chain encountered an integration of performance of all elements of the chain. As such managing the overall supply chain efficiency (performance level) is definitely a serious as well as challenging task.

'Performance' implies predetermined parameters and 'measurement' implies on the ability to monitor events and ongoing activities in a systematic as well as a logical way. A number of approaches for measuring performance were highlighted in past literature like balanced scorecard (Kaplan and Norton, 1992; 1997), the performance measurement matrix (Keegan et al, 1989) performance measurement questionnaire (Dixon et al, 1990), criteria for measurement system design (Globerson, 1985) and computer aided manufacturing approaches. However, exploration of those highlights a range of inherent shortcomings including, lack of strategic focus, forcing managers to encourage local optimization rather than seeking the continuous improvement and also they are disable to provide adequate information about competitors.

However, since increasing demands for quick order fulfillment and fast delivery, new trends have emerged. As such, in addition to usual financial measures, other specific criterions (indicators) such as customer's satisfaction should also be considered. Emerge of multiple performance measures has made the efficiency measurement task, complex and sophisticated. Also the toll utilizing to measure the performance should not only provide quantitative reasoning but should also provide qualitative perspective to remain aligned with strategic goals of the organization (Shafiee and Shams-e-alam, 2011).

To this end, present work emphasizes on development of efficient Decision Support Systems (DSS) towards performance appraisement of organizational supply chain, as a whole. The study articulates different evaluation criterions (multi-dimensions) in relation to strategic, tactical as well as operational level of the entire supply chain. Subjectivity associated with qualitative evaluation factors (indices) on appraisement of overall SC performance extent has been tackled through logical exploration of fuzzy logic as well as grey theory.

This work postulates the problem of SC performance appraisement from a decision making point of view. The said problem has been considered here as a Multi-Criteria Decision Making (MCDM) involving participation of a group of decision-makers (DMs)/experts. The appraisement frameworks (modules) thus proposed in this research are capable of utilizing DM's expertise (in terms of linguistic scale) logically and systematically supported by fuzzy as well as grey theory, respectively. Proper utilization of fuzzy (or grey) based appraisement modules may facilitate managerial decision making towards SC performance appraisement as well as performance benchmarking.

In this context, various advantages of exploring fuzzy logic as well as grey theory in course of SC performance assessment and related decision making have been summarized below.

Fuzzy logic (FL) is a multivalued logic that allows intermediate values to be defined between conventional evaluations, such as TRUE/FALSE, YES/NO, HIGH/LOW. The basic concept underlying fuzzy logic theory is that of a linguistic variable - a variable whose values are words rather than numbers (crisp). This allows notions, (linguistic terminology) to be formulated mathematically and processed by computers in order to apply a more human-like way of thinking in the programming of computers (Baldwin, 1981; Vadiee and Jamshidi, 1994; Dorsey and Coovert, 2003). FL is derived from fuzzy set theory dealing with reasoning that is approximate rather than precise. In the traditional set theory, an element either belongs to a set or does not. However, in FL, membership functions classify elements in the range [0, 1], with 0 and 1 being no and full inclusion, respectively. Much of FL may be viewed as a methodology for computing with words rather than numbers. Although words are inherently less precise than numbers, their use is closer to human intuition (Kruse et al., 1994). The principal objective of FL is to formalize the remarkable capability of humans to reason, solve problems, and make decisions in an environment of uncertainty, imprecision, incompleteness of information and partiality of knowledge, truth, and class membership.

Fuzzy logic thus provides engineers with a clear and intuitive way to implement control systems, decision making and diagnostic systems in various branches of industry. Fuzzy rules can emulate an experienced human operator in real time, e.g. select appropriate ingredients, components or machines according to specific situations in the manufacturing process (Carr and Shearer, 2007).

According to (Agami et al., 2010), FL is the best candidate for the following reasons:

1) It provides a good solution to reasoning with uncertainty;
2) It can be built on top of the experience of experts;
3) It is tolerant for imprecise information, i.e., expert judgments;
4) It does not need historical data because the output depends on the evaluation of a predefined (by experts) set of rules;
5) It is easy to generate fuzzy rules using survey data without much preprocessing.

Fuzzy logic can be viewed as a problem solving methodology that provides a simple way of definite conclusions from vague and imprecise information. However, much of the information related to supply chain performance assessment is not quantifiable and precise with crisp boundaries (purely qualitative). Rather, this information is presented in expressions or words in natural language and without precision. Fuzzy logic models are capable of providing a reasonable solution to these common situations, though may be easily converted into human linguistic form constructed from semantics.

Fuzzy set theory (Zadeh, 1965) was developed in order to address contexts in which decision-makers (DMs) need to accurately analyze and process information that is imprecise in nature. Fuzzy sets provide a conceptual framework, as well as perform as an analytical tool to solve real world problems where there is a lack of specific facts and precision (Baldwin, 1996; Klir and Yuan, 1995). However, the application of fuzzy set theory towards management decisions has been generally lacking despite its potential value in many common situations (Dorsey and Coovert, 2003). Nevertheless, human semantics are embedded in the meaning of fuzziness and comparison (Zadeh, 1983). On the other hand, the usage of multi granularity linguistic information can eliminate the difference from evaluators (Herrera et.al, 2000).

The part of the present work aims to present different approaches (frameworks/modules) to incorporate a qualitative forward looking ability in measuring the supply chain performance using fuzzy logic concept. According to (Patidar and Sohani, 2013) performance measurement and metrics play important role to setting objective, evaluating performance and determining future course of action. The fuzzy logic needs to be applied on the metrics of supply chain operational reference model and it may help the managers in realistic decision making.

Today, many decision indexes in most decision making subjects are qualitative or the existing information about them is uncertain. Thus, necessity of using efficient models which can analyze conditions of decision and achieve an accurate decision becomes obvious (Aghajani and Hadi-Vencheh, 2011).

Grey system theory is a relatively new method for studying uncertain problem with less data and poor information. The new theory studies on the “small sample”, “poor information” systems with “partial information known, partial information unknown”. It describes correctly and monitors effectively system’s operation and evolution, through extracting valuable information from known information. Grey system theory has come into being with development of system sciences group and uncertainty system theory and methods, and conforms to current system science and uncertain system theory. It is also the result of deepening perceptivity to uncertain system. [Source: Liu and Forrest, 2007]

Grey theory (Deng, 1982; Nagai and Yamaguchi, 2004) is one of the methods that are used to study uncertainty; it is superior in mathematical analysis of systems with uncertain information. Up to present, fuzzy based approach has been proposed to deal with the suppliers’ selection problem under certainty (Wang, 2005). The advantage of grey theory over fuzzy set theory (Zadeh, 1965; Bellman and Zadeh, 1970) is that grey theory considers the condition of the fuzziness. That is, grey theory can flexibly deal with the fuzziness situation (Xia, 2000).

Grey systems theory comes into being with the development of systems science’s group and uncertainty systems theory and methods, and conforms to the current systems science and uncertain systems theory. It is also the result of deepening perceptivity about uncertain systems. [Source: Liu and Forrest, 2007]

Grey system based methods provide various tools to cope with situations of limited data, such as correlation analysis and modeling. It aims to deal with the uncertainty of a system by using elements of relational analysis, operational research, system control, system modeling and system forecasting. Through quantitative analysis of Grey relation, it provides more accurate and subjective data. Most distinguished Grey theory methods that are in use are Grey relational analysis and Grey modeling.

[Source: Sifen and Forrest, 2007; Chih-Hung et al., 2003; Slavek and Jović, 2012]

The three terms that are typical symbols and features of Grey System are (Chih-Hung et al., 2003):

a) The Grey number in Grey system is a number with incomplete information.

b) The Grey element represents an element with incomplete information.

c) The Grey relation is the relation with incomplete information.

The Grey system thus provides multidisciplinary approaches for analysis and abstract modeling of systems for which the information is limited, incomplete and characterized by random uncertainty (Sifen and Forrest, 2007).

In view of various advantages of grey theory in decision-information sciences; in the present work, apart from developing fuzzy based performance appraisement modules (Decision Support Systems), grey theory has also been attempted in framing efficient DSS tools to aid overall SC performance appraisement as well as benchmarking.

The prime objectives of the present work have been furnished below.

**1. Exploration of multi-level (integrated) evaluation hierarchy, also called evaluation index system (consisting of SC performance measures and metrics/ main indices as well as sub-indices) towards estimation of overall SC performance extent.**

**2. Exploration of fuzzy logic as well as grey theory to develop efficient as well as flexible decision support tools for systematic and logical appraisement of SC performance.**

**3. Identification of ill (poor)-performing areas of SC.** "ILL areas'' of SC have been referred as poor-performing areas. In this research, a General Hierarchy Criteria (GHC) has been conceptualized in pursuit of determining an overall performance index of the industrial SC. The said GHC consists of multi-layered evaluation index system in which main evaluation criterions have further been divided into a number of sub-criterions. The performance extent of individual sub-criterions contributes to the overall SC's performance metric. Therefore, based on computed FPII (Fuzzy Performance Importance Index), sub-criterions have been ranked in accordance with their performance degree. Lower ranking order assumes greater extent of performance; whereas, higher ranking order is the symptom (indicator) of poor (ill)-performing areas.

**4. Benchmarking of SC performance extent.**

**5. Ranking (and selection of the best) of alternative industries/enterprises (running under similar SC architecture) in view of ongoing SC overall performance.** This is a theoretical work based on the empirical data aims to rank alternative organizations (running under similar SC construct) with respect to their overall performance index of the SC. The alternatives selected here are imaginary. It is performance benchmarking of other companies in the same industry. Because, it has been assumed that alternative companies should run under similar supply chain construct.

The aforesaid objectives are also important and relevant in the context of SCM in India.

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However, some Indian companies are moving towards making their supply chain and logistics efficient, most of them have done very little or nothing. If companies choose to compete in the global environment, they will have to look for ways to reduce expenditures of their suppliers and channel partners, logistics or distribution partners. This reduction in cost will lead the revamping of supply chains and significant investment in information technology, because information technology tools and techniques plays very important role in improving the status of the SCM (Reddy et al., 2012).

## 1.4 Organization of the Present Dissertation

The organization of the present dissertation is as follows. **CHAPTER 1** (**Research Background)** provides an in-depth understating of research agenda through an exhaustive literature review collected from reputed journals, published books, industry magazines, technical notes as well as proceedings of past conferences. The importance of SC overall performance evaluation and in doing so the shortcomings of existing performance appraisement approaches as documented in literature have been clearly pointed out. The basic necessity of considering qualitative (subjective) evaluation criterions in appraising overall SC performance extent and importance of experts' participation in such a decision making task have been well understood. Based on the extensive literature review followed by acquiring a clear idea about the existing research gap; the prime objectives of the present research have been identified and planned to investigate accordingly. **CHAPTER 2** (**Supply Chain Performance Appraisement and Benchmarking: A Modified Version of Deng's Similarity Measure Approach Combined with Fuzzy Set Theory)** exhibits a decision support framework through utilizing modified Deng's similarity measure approach in combination with fuzzy logic for SC performance appraisement and benchmarking. **CHAPTER 3** (**Supply Chain Performance Assessment in Fuzzy Context)** develops fuzzy embedded performance evaluation modules by exploring theories of generalized fuzzy numbers as well as generalized interval valued fuzzy numbers set theory, respectively. An overall SC performance evaluation index has been computed in terms of fuzzy number. This chapter also suggests methodologies to identify ill-performing areas of the SC under consideration. The concepts of ranking fuzzy numbers by 'maximizing set and minimizing set' as well as the idea of 'fuzzy degree of similarity' have been adapted to facilitate in understanding existence of different ill-performing elements in the SC network. **CHAPTER 4** (**Supply Chain Performance Benchmarking by Fuzzy-MULTIMOORA)** develops a methodological framework towards deriving performance ranking order (benchmarking) of candidate alternative industries/enterprises (operating under similar SC structure) by utilizing fuzzy logic embedded MULTI-MOORA (Multi-Objective Optimization by Ratio Analysis). Similar benchmarking problem has been solved by fuzzy grey relation method and presented in **CHAPTER 5** (**Supply Chain Performance Benchmarking by Fuzzy Grey Relation Method)**. Exploration of grey numbers theory as well as grey-MULTIMOORA towards SC performance benchmarking has been attempted in **CHAPTER 6** (**Supply Chain Performance Benchmarking by Grey Theory and Grey-MULTIMOORA)**. **CHAPTER 7** (**Executive Summary and Conclusions: Future Research Directions)** presents summary of the entire research work presented in the dissertation followed by conclutions. Contributions of the present research as well as future research directions have been pointed out too.

The chonology of the work reported in this dissertation has been presented in Fig. 1.1.

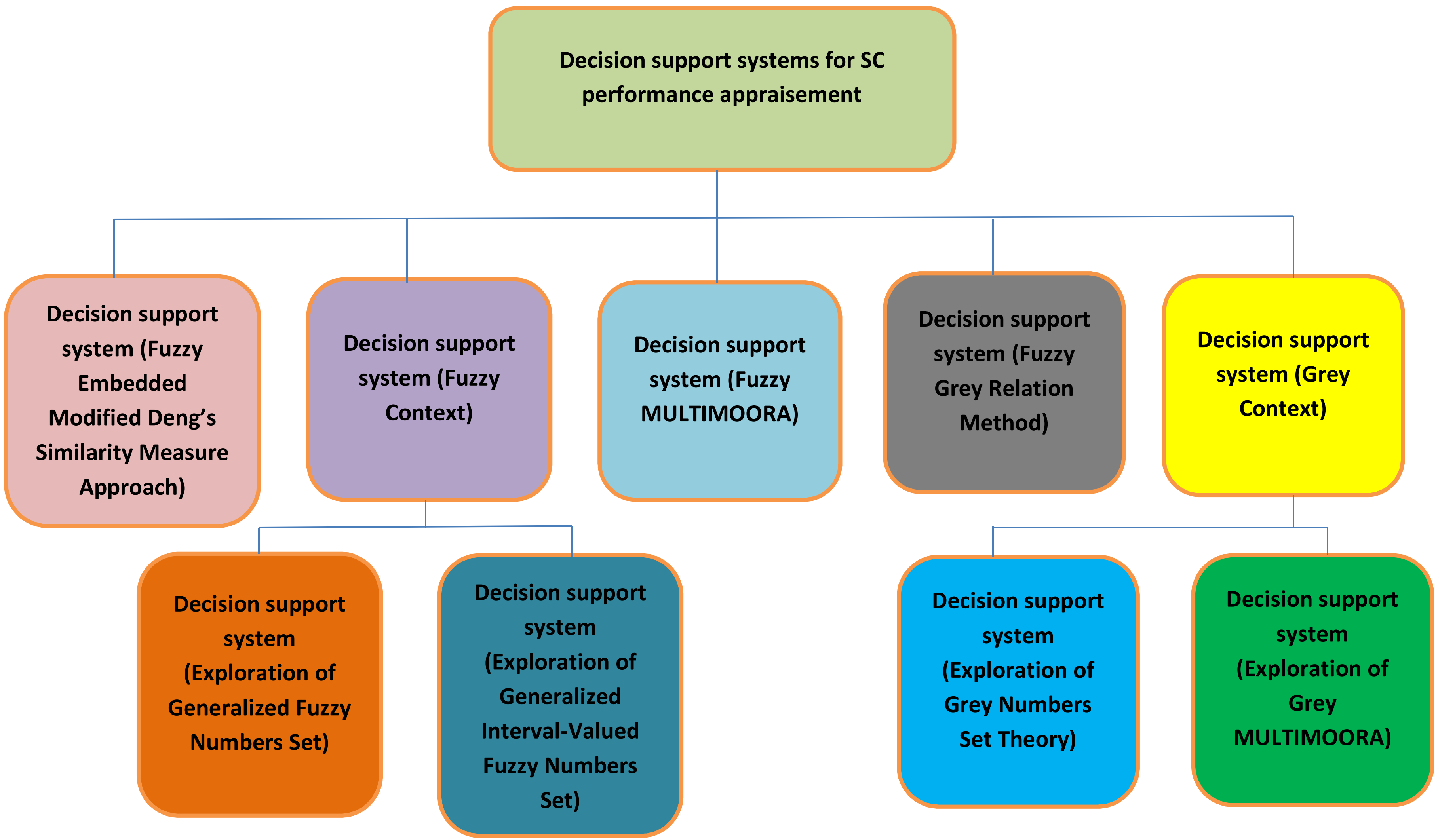


Fig. 1.1: Outline of the work carried out in this dissertation

# CHAPTER 2

## Supply Chain Performance Appraisement and Benchmarking: A Modified Version of Deng's Similarity Measure Approach Combined with Fuzzy Set Theory

## 2.1 Overview

Supply chain management (SCM) has become an important avenue in modern business scenario. It brings revolutionary philosophy towards effective business management along with sustained competitiveness. Successful implementation of supply chain strategies to gain competitive advantage in the marketplace necessitates effective evaluation as well as monitoring of supply chain performance extent. In this context, the present work attempts to explore an efficient Decision-Support System (DSS) towards supply chain performance appraisement as well as benchmarking using a modified similarity approach. Most of the supply chain performance measures and metrics being subjective in nature; the study explores the concept of fuzzy logic in order to collect expert judgment in relation to appropriateness rating (performance extent) of individual SC performance indices as well as their priority weights. The crisp score (obtained from Incentre of Centroids method of fuzzy theory) has been utilized as the numeric representative value in order to convert subjective evaluation information into a mathematic base. Moreover, a new similarity method (modified similarity method), which is the extension of Deng's similarity measure concept has been explored here to facilitate such a decision-making problem. The performance ranking order of alternative industries that run under similar SC strategies, thus obtained by the aforesaid modified similarity method has been compared to that of TOPSIS (*Technique for Order Preference by Similarity to Ideal Solution*). The study exhibits application feasibility of the modified similarity method towards SC performance measurement, benchmarking and related decision-making.

## 2.2 Research Background

SCM is being viewed as a major component of competitive strategy in order to enhance organizational productivity as well as profitability. In recent years, organizational performance measurement and metrics have received much attention from academicians, industrialists as well as management practitioners. The role of these measures and metrics in the success of an organizational supply chain cannot be overstated because they affect strategic, tactical and operational planning and control. Performance measurement and metrics have an important role to play in setting organizational goals and objectives, evaluating performance, and determining future courses of actions (Gunasekaran et al., 2004).

Gunasekaran et al. (2001) developed a framework for measuring the strategic, tactical and operational level performance in a supply chain. The authors emphasized on performance measures dealing with suppliers, delivery performance, customer-service, and inventory and logistics costs in a SCM. Kleijnen and Smits (2003) dealt with multiple metrics in SCM via the balanced scorecard which measured customers, internal processes, innovations, and finance. This paper distinguished four simulation types for SCM: (i) spreadsheet simulation, (ii) system dynamics, (iii) discrete-event simulation, and (iv) business games. These simulation types might explain the bullwhip effect, predict fill rate values, and educate and train users. Wang et al. (2004) attempted to relate product characteristics to supply chain strategy and to adopt supply chain operations reference (SCOR) model level I performance metrics as the decision criteria. An integrated analytic hierarchy process (AHP) and preemptive goal programming (PGP) based multi-criteria decision-making methodology was developed to take into account both qualitative and quantitative factors in supplier selection. Li et al. (2006) conceptualized five dimensions of SCM practice (strategic supplier partnership, customer relationship, level of information sharing, quality of information sharing, and postponement) and tested the relationships between SCM practices, competitive advantage, and organizational performance. Angerhofer and Angelides (2006) showed how the constituents, key parameters and performance indicators were modeled into the decision making environment. The authors illustrated how the decision support environment might be used to improve the performance of a collaborative supply chain by pinpointing areas for improvement.

Shepherd and Gunter (2006) provided taxonomy of performance measures followed by a critical evaluation of measurement systems designed to evaluate the performance of supply chains. The paper argued that despite considerable advances in the literature in recent years, a number of important problems had not yet received adequate attention, including: the factors influencing the successful implementation of performance measurement systems for supply chains; the forces shaping their evolution over time; and, the problem of their ongoing maintenance. Chen and Wang (2006) proposed a fuzzy cognitive map (FCM) simulation model for the sample performance measurement system of Internet-based supply chain, which was constructed by (Balanced Score Card) BSC theory. The authors cited examples to explain how FCM could be adapted to execute the causal mechanism of BSC, and also how FCM could support group decision-making and forecasting in performance measurement. Berrah and Clivillé (2007) dealt with the supply chain (SC) performance formalization. The authors proposed to build performance measurement systems (PMSs) by linking an overall performance expression to elementary ones.

Bhagwat and Sharma (2007) developed a balanced scorecard for supply chain management that measured and evaluated day-to-day business operations from following four perspectives:

finance, customer, internal business process, and learning and growth. Wong and Wong (2007) illustrated the use of data envelopment analysis (DEA) in measuring internal supply chain performance. The information obtained from the DEA models helped managers to identify the inefficient operations and take the right remedial actions for continuous improvement. Aramyan et al. (2007) evaluated the usefulness of a novel conceptual model for supply chain performance measurement in an agri-food supply chain. It was concluded that four main categories of performance measures (i.e. efficiency, flexibility, responsiveness, and food quality) were identified as key performance components of the supply chain performance measurement system. Kamalabadi et al. (2008) presented an efficient approach to supply chain performance measurement by the exploration of FMADM (Fuzzy Multi Attribute Decision Making) method.

A supply chain embodies all such activities that influence timing, cost, quality and delivery of a product. Increased competitiveness has forced the supply chains to create new standards for improving processes. Since a benchmark is a standard that is aspired by observing a best practice, it is of immense importance in SCM. Also, supply chains are rooted with the 'extended' concept meaning that it includes suppliers, distributors and various processes involving them. Thus a single performance measure does not suffice for the entire chain. Therefore, Benchmarking and Supply chain performance measures are of prime importance in supply chain management context (Wong and Wong, 2008; Khare et al., 2012).

Xu et al. (2009) studied the supply chain performance evaluation of a furniture manufacture industry in the southwest of China. The authors identified the main uncertainty factors affecting evaluation process, and then modeled and analyzed those using rough data envelopment analysis (RDEA). Thakkar et al. (2009) proposed an integrated supply chain performance measurement framework for the case of small and medium scale enterprises (SMEs). This study integrated the salient features of balanced scorecard (BSC) and supply chain operation reference (SCOR) model to deliver a comprehensive performance measurement framework for SMEs. Keebler and Plank (2009) described the state of logistics performance measurement in corporations based in the USA. This paper provided a benchmark for organizations assessing the quality of their logistics performance measurement practices and helped to identify opportunities for significant improvement. Cai et al. (2009) proposed a framework towards improving the iterative key performance indicators (KPIs) accomplishment in a supply chain context. The proposed framework quantitatively analyzed the interdependent relationships amongst a set of KPIs. It could identify crucial KPI accomplishment costs and propose performance improvement strategies for decision-makers (DMs) in a supply chain. Olugu and Wong (2009) identified an unified direction of research in the supply chain performance measurement using fuzzy logic operation in measuring the uncertainty and ambiguity surrounding supply chain performance measurement. Elgazzar et al. (2011) proposed new software (SW) application utilizing the SCOR FAHP technique which incorporated the Fuzzy Analytic Hierarchy Process (FAHP) method in the Supply Chain Operations Reference-Model (SCOR) for the purpose of evaluating and improving supply chain operations' performance. Özkir and Demirel (2011) revealed the relationship amongst key performance indicators of a supply chain. This research explored the strategies for design and performance measurement of different supply chain types based on fuzzy entropy approach. Cuthbertson and Piotrowicz (2011) proposed a framework for the empirical analysis of supply chain performance measurement systems used in different supply chain contexts. The proposed framework could help to develop performance measurement systems that were suitable for certain organizational and supply chain contexts in which a company operated, as well as to compare different systems used across different supply chains.

El-Baz (2011) presented a fuzzy decision making approach to deal with the performance measurement in supply chain systems. This paper presented a performance measurement approach based on fuzzy set theory and the pair-wise comparison of Analytical Hierarchy Process (AHP), which ensured the consistency of the designer's assignments of importance of one factor over another to find the weight of each of the manufacturing activity in the departmental organization. In the proposed model, various input factors were selected, and treated as a linear membership function of fuzzy type. The approach provided an effective decision tool for the performance measurement of a supply chain in manufacturing environment. Elgazzar et al. (2012) developed a performance measurement method which linked supply chain (SC) processes' performance to a company's financial strategy through demonstrating and utilizing the relationship between SC processes' performance and a company's financial performance. The Dempster Shafer/Analytical Hierarchy Processes (DS/AHP) model was employed to link SC processes' performance to the company's financial performance through determining the relative importance weights of SC performance measures with respect to the priorities of financial performance. The paper also introduced a Supply Chain Financial Link Index (SCFLI) to test the extent to which SC processes' performance was linked to the company's financial strategic objectives. This index offered an effective supply chain management (SCM) tool to provide continuous feedback on SC performance and identified the appropriate corrective actions. Bai et al. (2012) introduced a methodology to help evaluate, select, and monitor sustainable supply chain performance measurement that could be integrated into a performance management system (PMS). Grey-based neighborhood rough set theory was used to help arrive at a core set of important business and environmental performance measures for sustainable supply chains. The supply chain operations reference (SCOR) model was used to develop both business and environmental measures for supply chain sourcing. Malkhalifeh and Mollaeian (2012) introduced a non-radial network DEA model for evaluating supply chain performance, by considering intermediate production. Chandraker and Kumar (2013) used MCDM (Multi-Criteria decision making) for determining green supply chain management (GSCM) performance. Fuzzy comprehensive method was applied to get the performance having different environmental, operational, economic performance parameters, after gating performance, comparing the comprehensive performance before and after the implementation of the green supply chain for Chhattisgarh manufacturing industry. Hong and Hua (2013) addressed Supply Chain Dynamic Performance Measurement Based on BSC and Support Vector Machine (SVM). Patidar and Sohani (2013) presented an approach to incorporate a qualitative forward looking ability in measuring the supply chain performance using fuzzy logic concept.

Industrial organizations are moving toward more integrated supply chains (SCs) to remain competitive. To be effectively designed and managed, these SCs need to be measured and evaluated in terms of performance in a consistent way. For this reason, it is important to acquire a common and unified understanding of the SC associated performance, process and structure concepts (Böhm et al., 2007).

In this context, the present study aims to address the issues of supply chain performance measurement, benchmarking and related decision making. Performance measurement is the process of qualifying the efficiency and effectiveness of the supply chain (Sillanp and Kess, 2012). This study explores a framework for supply chain performance appraisement and benchmarking using modified Deng's similarity approach. The result obtained thereof, has been compared with that of TOPSIS method. Finally, the study infers the effectiveness of the new similarity measure approach in relation SC performance appraisement.

## 2.3 Concept of Similarity Based Method

There are several methods for expressing conflict between two variables in multi-criteria analysis problems (Carlsson and Fuller, 1995; Diakoulaki et al., 1995; Zeleny, 1998). Among them, the notion of variable's gradient explains conflict between decision criteria in multi-criteria analysis problems, which is very common (Cohon, 1978). Using this method, a conflict index is calculated between two alternatives to show the degree of conflict between the alternatives.

Assuming that $A_i$ and $A_j$ are the two alternatives concerned in a given multi-criteria analysis problem, these two alternatives can be considered as two vectors in the $m$ dimensional real space. The angle between $A_i$ and $A_j$ in the $m$ dimensional real space is a good measure of conflict between them. As shown in Fig. 2.1, $A_i$ and $A_j$ are in no conflict if $\theta_{ij} = 0$, the conflict is possible if $\theta_{ij} \neq 0$, i.e. $\theta_{ij} \in \left(0, \frac{\pi}{2}\right)$. This is so because when $\theta_{ij} = 0$ the gradients of both the alternatives $A_i$ and $A_j$ are simultaneously in the same increasing direction and there is no conflict between them. The situation of conflict occurs when $\theta_{ij} \neq 0$, i.e. when the gradients of $A_i$ and $A_j$ are not coincident.

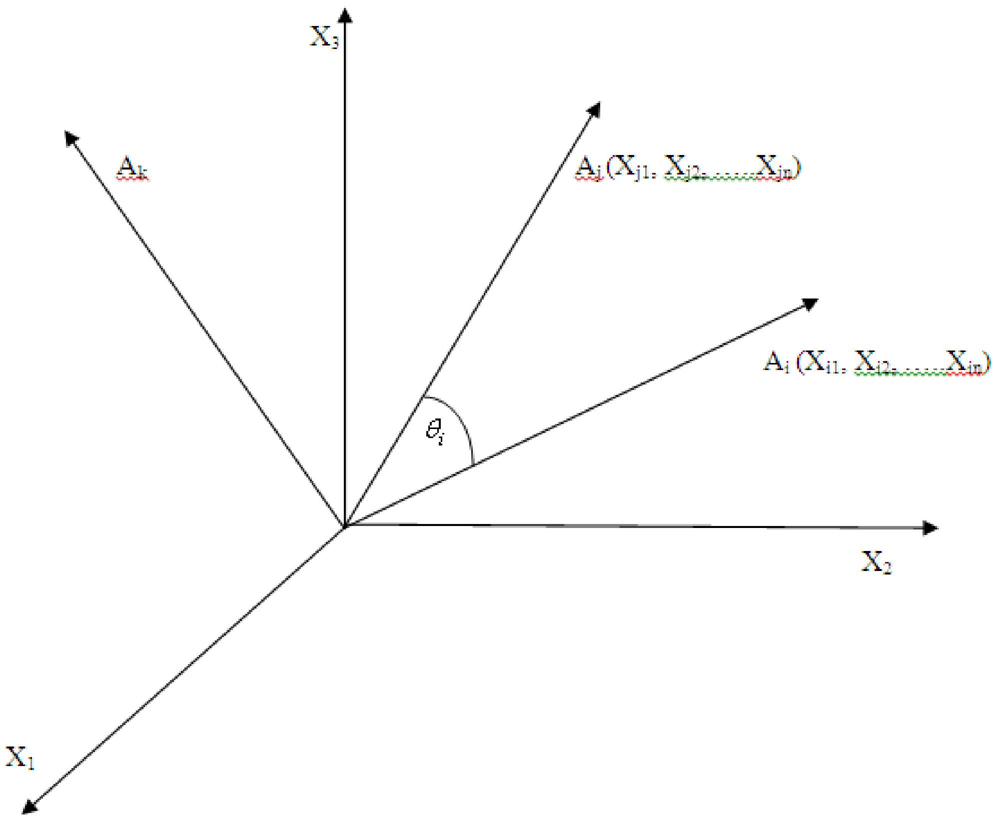


Fig. 2.1: Degree of conflict between alternatives by gradients

The degree of conflict between alternatives $A_i$ and $A_j$ is determined by:-

$$\cos\theta_{ij} = \frac{\sum_{k=1}^{m} x_{ij} x_{jk}}{\left(\sum_{k=1}^{m} x_{ik}^2\right)^{0.5} \left(\sum_{k=1}^{m} x_{jk}^2\right)^{0.5}} \quad (2.1)$$

Here $\theta_{ij}$ is the angle between the gradients of the two alternatives and $(X_{i1}, X_{i2}, ..., X_{im})$ and $(X_{j1}, X_{j2}, ..., X_{jm})$ are the gradients of two alternatives $A_i$ and $A_j$ respectively.

The conflict index equals to one characterized by $\theta_{ij} = 0$ as the corresponding gradient vectors lie in the same direction of improvement. Similarly, the conflict index is zero characterized by $\theta_{ij} = \frac{\pi}{2}$ which indicates that their gradient vectors have the perpendicular relationship with respect to each other.

## 2.3.1 Deng's Similarity Based Method

In this work it has used Deng's similarity-based method (Deng, 2007) to rank candidate alternatives. Deng described this method as follows.

Consider a multi-criteria decision matrix $X$; which consists of a total of $n$ number of alternatives and $m$ number of criterions. Here $x_{ij}$ represents $j_{th}$ criterion value for $i_{th}$ alternative. Also $w_j$ be the weight of $j_{th}$ criterion; where $(j = 1,2,...,m)$.

$$X = \begin{bmatrix} x_{11} & x_{12} & . & . & . & x_{1m} \\ x_{21} & x_{22} & . & . & . & x_{2m} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ x_{n1} & x_{n2} & . & . & . & x_{nm} \end{bmatrix} \quad (2.2)$$

$$W = \{w_1, w_2, ..., w_m\} \quad (2.3)$$

The concept of the ideal solution is used in such a way that the most preferred alternative should have the highest degree of similarity to the positive ideal solution and the lowest degree of similarity to the negative-ideal solution. The ranking method starts by normalizing the decision matrix to ensure all the criteria involved are advantageous (beneficial) in nature based on Eq. (2.4), described as:

$$x_{ij}^{'} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}}} \tag{2.4}$$

As a result, a normalized decision matrix can be determined as:

$$X^{'} = \begin{bmatrix} x_{11}^{'} & x_{12}^{'} & . & . & . & x_{1m}^{'} \\ x_{21}^{'} & x_{22}^{'} & . & . & . & x_{2n}^{'} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ x_{n1}^{'} & x_{n2}^{'} & . & . & . & x_{nm}^{'} \end{bmatrix} \tag{2.5}$$

The weighted performance matrix which reflects the performance of each alternative with respect to each criterion is determined by multiplying the normalized decision matrix in Eq. (2.4) by the weight vector, given as Eq. (2.5).

$$X^{''} = \begin{bmatrix} x_{11}^{'}w_1 & x_{12}^{'}w_2 & . & . & . & x_{1m}^{'}w_m \\ x_{21}^{'}w_1 & x_{22}^{'}w_2 & . & . & . & x_{2n}^{'}w_m \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ x_{n1}^{'}w_1 & x_{n2}^{'}w_2 & . & . & . & x_{nm}^{'}w_m \end{bmatrix} = \begin{bmatrix} y_{11}^{'} & y_{12}^{'} & . & . & . & y_{1m}^{'} \\ y_{21}^{'} & y_{22}^{'} & . & . & . & y_{2m}^{'} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ y_{n1}^{'} & y_{n2}^{'} & . & . & . & y_{nm}^{'} \end{bmatrix} \tag{2.6}$$

The positive (or negative) ideal solution consists of the best (or worst) criteria values attainable from all the alternatives if each criterion takes monotonically increasing or decreasing values (Deng et al., 2000). This concept has been widely used in various multi-criteria analysis models for solving practical decision problems (Deng, 1999). This is due to its simplicity and comprehensibility in concept, its computational efficiency and its ability to measure the relative performance of the decision alternatives in a simple mathematical form. Based on this concept, the positive ideal solution and the negative ideal solution can be determined from the performance matrix in Eq. (2.6), given as:

$$\begin{cases} A^{+} = \left(y_1^{+}, y_2^{+}, \ldots, y_m^{+}\right) \\ A^{-} = \left(y_1^{-}, y_2^{-}, \ldots, y_m^{-}\right) \end{cases} \tag{2.7}$$

Here,

$$\begin{cases} y_j^{+} = Max\left(y_{ij}\right)\big|_{i=1,2,\ldots,n} \\ y_j^{-} = Min\left(y_{ij}\right)\big|_{i=1,2,\ldots,n} \end{cases} \tag{2.8}$$

Also, $A_i = \left(y'_{i1}, y'_{i2}, \ldots, y'_{im}\right)$

The degree of conflict between each alternative $A_i$ and the positive ideal solution (the negative ideal solution) can be determined based on Eq. (2.1), given as:

$$A_i, A^{\pm} = |A_i||A^{\pm}|\cos\theta_i^{\pm}$$

$$A_i, A^{\pm} = \sum_{j=1}^{m} y'_{ij} y_j^{\pm}$$

Here, $\begin{cases} |A_i| = \sum_{j=1}^{m} y_{ij}^{'2} \\ A^{\pm} = \sum_{j=1}^{m} \left(y_j^{\pm}\right)^2 \end{cases}$

$$\begin{cases} \cos\theta_i^{+} = \dfrac{\sum_{j=1}^{m} y'_{ij} y_j^{+}}{\left(\sum_{j=1}^{m} y_{ij}^{'2}\right)^{0.5} \left(\sum_{j=1}^{m} \left(y_j^{+}\right)^2\right)^{0.5}} \\ \cos\theta_i^{-} = \dfrac{\sum_{j=1}^{m} y'_{ij} y_j^{-}}{\left(\sum_{j=1}^{m} y_{ij}^{'2}\right)^{0.5} \left(\sum_{j=1}^{m} \left(y_j^{-}\right)^2\right)^{0.5}} \end{cases} \tag{2.9}$$

As a consequence, the degree of similarity between each alternative $A_i$ and the positive and the negative ideal solution can be determined by Eq. (2.10)

$$|C_i| = \cos\theta_i^{\pm} \times |A_i|$$

$$|C_i| = \frac{\sum_{j=1}^{m} y'_{ij} y_j^{\pm}}{\left(\sum_{j=1}^{m} y_{ij}^{'2}\right)^{0.5} \times \left(\sum_{j=1}^{m} \left(y_j^{\pm}\right)^2\right)^{0.5}} \times \left(\sum_{j=1}^{m} y_{ij}^{'2}\right)^{0.5}$$

$$S_i^{\pm} = \frac{|C_i|}{|A^{\pm}|} = \frac{\cos\theta_i^{\pm} \times |A_i|}{\left(\sum_{j=1}^{m} \left(y_j^{\pm}\right)^2\right)^{0.5}} = \frac{\cos\theta_i^{\pm} \times \left(\sum_{j=1}^{m} y_{ij}^{'2}\right)^{0.5}}{\left(\sum_{j=1}^{m} \left(y_j^{\pm}\right)^2\right)^{0.5}} \tag{2.10}$$

The larger the $S_i$, the higher is the degree of similarity between alternative $A_i$ and $A_j$. An overall performance index can then be calculated for each alternative across all criteria based on the degree of similarity of alternative $A_i$ relative to the ideal solution as:

$$P_i = \frac{S_i^{+}}{S_i^{+} + S_i^{-}} \tag{2.11}$$

The larger the index value, the more preferred the alternative is.

### 2.3.2 Modified Similarity Method

In the Deng's Similarity based method, the Eq. (2.10) is used to obtain $S_i^{-}$ and $S_i^{+}$. According to this method, if an alternative has the most similarity to positive ideal solution and least similarity to the negative ideal solution, then it will be the best. Safari et al. (2013) cited an example which showed that the best real alternative had the most similarity with negative ideal alternative (solution). It was, therefore, concluded that Deng made a mistake in the formula negative similarity $\left(S_i^{-}\right)$. Whereby the Deng's Similarity method hasn't been indicated in this point will be performed as below.

$$A_i = \left(y'_{i1}, y'_{i2}, \ldots, y'_{im}\right); (i = 1,2,\ldots,n)$$

$$\begin{cases} A^{+} = \left(y_1^{+}, y_2^{+}, \ldots, y_m^{+}\right) \\ A^{-} = \left(y_1^{-}, y_2^{-}, \ldots, y_m^{-}\right) \end{cases}$$

$$\cos\theta_i^{\pm} = \frac{\sum_{j=1}^{m} y_{ij}^{'} y_j^{\pm}}{\left(\sum_{j=1}^{m} y_{ij}^{'2}\right)^{0.5} \left(\sum_{j=1}^{m} \left(y_j^{\pm}\right)^2\right)^{0.5}}$$

$$\left|C_i^{\pm}\right| = \cos\theta_i^{\pm} \times \left|A_i\right|$$

$$\left|C_i^{\pm}\right| = \frac{\sum_{j=1}^{m} y_{ij}^{'} y_j^{\pm}}{\left(\sum_{j=1}^{m} y_{ij}^{'2}\right)^{0.5} \times \left(\sum_{j=1}^{m} \left(y_j^{\pm}\right)^2\right)^{0.5}} \times \left(\sum_{j=1}^{m} y_{ij}^{'2}\right)^{0.5}$$

$$S_i^{+} = \frac{\left|C_i^{+}\right|}{\left|A^{+}\right|} = \frac{\cos\theta_i^{+} \times \left|A_i\right|}{\left(\sum_{j=1}^{m} \left(y_j^{+}\right)^2\right)^{0.5}} = \frac{\cos\theta_i^{+} \times \left(\sum_{j=1}^{m} y_{ij}^{'2}\right)^{0.5}}{\left(\sum_{j=1}^{m} \left(y_j^{+}\right)^2\right)^{0.5}} \text{ and} \tag{2.12}$$

$$S_i^{-} = \frac{\left|A^{-}\right|}{\left|C_i^{-}\right|} = \frac{\left(\sum_{j=1}^{m} \left(y_j^{-}\right)^2\right)^{0.5}}{\cos\theta_i^{-} \times \left|A_i\right|} = \frac{\left(\sum_{j=1}^{m} \left(y_j^{-}\right)^2\right)^{0.5}}{\cos\theta_i^{-} \times \left(\sum_{j=1}^{m} y_{ij}^{'2}\right)^{0.5}} \tag{2.13}$$

Another point that should be considered is a noticeable difference between this method (modified similarity method) and TOPSIS (*Technique for Order Preference by Similarity to Ideal Solution*). Overall performance of TOPSIS method is designed based on logic which comes to one (when $A_i = A^{+}$) in the best situation and comes to zeros (when $A_i = A^{-}$) in the worst situation (Tzeng and Huang, 2011). In the modified similarity method due to the reason that the alternative $A_i$ has an unclear angle with negative (positive) ideal solution when it is equal to the positive (negative) ideal solution, therefore, overall performance doesn't become equal one (zero).

## 2.4 Procedural Hierarchy for Solving MCDMs Problems using Modified Similarity Method

**Step 1:** Determine the decision matrix as in Eq. (2.2).

**Step 2:** Determine the weighting vector as in Eq. (2.3).

**Step 3:** Normalize the decision matrix as in Eq. (2.5) which has been obtained by Eq. (2.2) and Eq. (2.4).

**Step 4:** Calculate the performance matrix as expressed in Eq. (2.6).

**Step 5:** Determine the positive ideal solution and the negative ideal solution by Eq. (2.7) and Eq. (2.8).

**Step 6:** Calculate the degree of conflict between each alternative and positive ideal solution and negative ideal solution by Eq. (2.9).

**Step 7:** Calculate the degree of similarity between alternatives and the positive ideal solution and the negative-ideal solution by Eq. (2.12) and Eq. (2.13).

**Step 8:** Calculate the overall performance index for each alternative across all criteria by Eq. (2.11).

**Step 9:** Rank the alternatives in the descending order of the index value.

## 2.5 Fuzzy Preliminaries

To deal with vagueness in human thought, Zadeh (1965) first introduced the fuzzy set theory, which has the capability to represent/manipulate data and information possessing based on non-statistical uncertainties. Moreover fuzzy set theory has been designed to mathematically represent uncertainty and vagueness and to provide formalized tools for dealing with the imprecision inherent to decision making problems. Some basic definitions of fuzzy sets, fuzzy numbers and linguistic variables are reviewed from Zadeh (1975), Buckley (1985), Negi (1989), Kaufmann and Gupta (1991). The basic definitions and notations below will be used throughout this thesis until otherwise stated.

### 2.5.1 Definitions of Fuzzy Sets

**Definition 1:** A fuzzy set $\tilde{A}$ in a universe of discourse $X$ is characterized by a membership function $\mu_{\tilde{A}}(x)$ which associates with each element $x$ in $X$ a real number in the interval $[0,1]$. The function value $\mu_{\tilde{A}}(x)$ is termed the grade of membership of $x$ in $\tilde{A}$ (Kaufmann and Gupta, 1991).

**Definition 2:** A fuzzy set $\tilde{A}$ in a universe of discourse $X$ is convex if and only if

$$\mu_{\tilde{A}}(\lambda x_1 + (1-\lambda)x_2) \geq \min\left(\mu_{\tilde{A}}(x_1), \mu_{\tilde{A}}(x_2)\right)$$

(1)

For all $x_1, x_2$ in $X$ and all $\lambda \in [0,1]$, where $\min$ denotes the minimum operator (Klir and Yuan, 1995).

**Definition 3:** The height of a fuzzy set is the largest membership grade attained by any element in that set. A fuzzy set $\tilde{A}$ in the universe of discourse $X$ is called normalized when the height of $\tilde{A}$ is equal to 1 (Klir and Yuan, 1995).

### 2.5.2 Definitions of Fuzzy Numbers

**Definition 1:** A fuzzy number is a fuzzy subset in the universe of discourse $X$ that is both convex and normal. Fig. 2.2 shows a fuzzy number $\tilde{n}$ in the universe of discourse $X$ that conforms to this definition (Kaufmann and Gupta, 1991).

**Definition 2:** The $\alpha$-cut of fuzzy number $\tilde{n}$ is defined as:

$$\tilde{n}^{\alpha} = \{x_i : \mu_{\tilde{n}}(x_i) \geq \alpha, x_i \in X\}, \qquad (2.14)$$

Here $\alpha \in [0,1]$.

The symbol $\tilde{n}^{\alpha}$ represents a non-empty bounded interval contained in $X$, which can be denoted by $\tilde{n}^{\alpha} = [n_l^{\alpha}, n_u^{\alpha}]$, $n_l^{\alpha}$ and $n_u^{\alpha}$ are the lower and upper bounds of the closed interval, respectively (Kaufmann and Gupta, 1991; Zimmermann, 1991). For a fuzzy number $\tilde{n}$, if $n_l^{\alpha} > 0$ and $n_u^{\alpha} \leq 1$

for all $\alpha \in [0,1]$, then $\tilde{n}$ is called a standardized (normalized) positive fuzzy number (Negi, 1989).

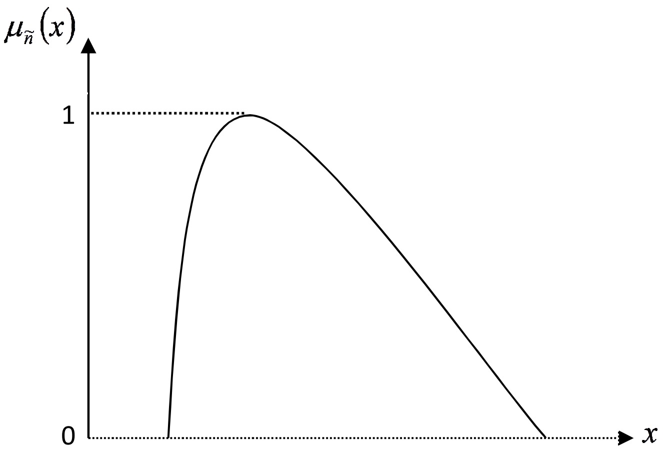


Fig. 2.2: A fuzzy number $\tilde{n}$

**Definition 3:** Suppose, a positive triangular fuzzy number (PTFN) is $\tilde{A}$ and that can be defined as $(a,b,c)$ shown in Fig. 2.3. The membership function $\mu_{\tilde{n}}(x)$ is defined as:

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-a)/(b-a), & \text{if } a \le x \le b, \\ (c-x)/(c-b), & \text{if } b \le x \le c, \\ 0, & \text{otherwise}, \end{cases} \tag{2.15}$$

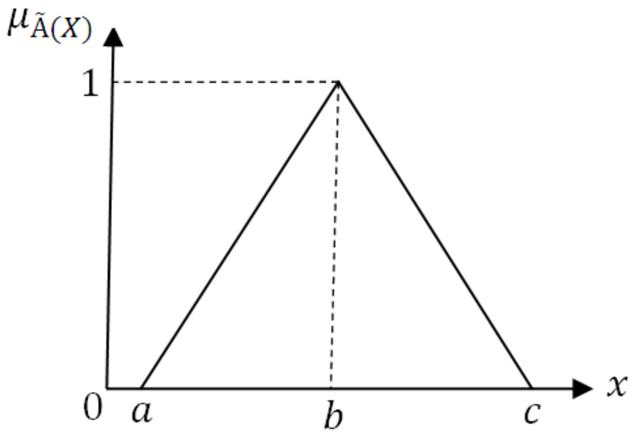


Fig. 2.3: A triangular fuzzy number $\tilde{A}$

Based on extension principle, the fuzzy sum $\oplus$ and fuzzy subtraction $\Theta$ of any two triangular fuzzy numbers are also triangular fuzzy numbers; but the multiplication $\otimes$ of any two triangular fuzzy numbers is only approximate triangular fuzzy number (Zadeh, 1975). Let's have a two positive triangular fuzzy numbers, such as $\tilde{A}_1 = (a_{1,} \, b_1, c_1)$, and $\tilde{A}_2 = (a_2, b_2, c_2)$, and a positive real number $r = (r, r, r)$, some algebraic operations can be expressed as follows:

$$\tilde{A}_1 \oplus \tilde{A}_2 = (a_1 + a_2, b_1 + b_2, c_1 + c_2) \quad (2.16)$$

$$\tilde{A}_1 \, \Theta \, \tilde{A}_2 = (a_1 - a_2, b_1 - b_2, c_1 - c_2), \quad (2.17)$$

$$\tilde{A}_1 \otimes \tilde{A}_2 = (a_1 a_2, b_1 b_2, c_1 c_2), \quad (2.18)$$

$$r \otimes \tilde{A}_1 = (ra_1, rb_1, rc_1), \quad (2.19)$$

$$\tilde{A}_1 \varnothing \tilde{A}_2 = (a_1/c_2, b_1/b_2, c_1/a_2), \quad (2.20)$$

The operations of $\vee\,(\max)$ and $\wedge\,(\min)$ are defined as:

$$\tilde{A}_1 (\vee) \tilde{A}_2 = (a_1 \vee a_2, b_1 \vee b_2, c_1 \vee c_2), \quad (2.21)$$

$$\tilde{A}_1 (\wedge) \tilde{A}_2 = (a_1 \wedge a_2, b_1 \wedge b_2, c_1 \wedge c_2), \quad (2.22)$$

Here, $r > 0$, and $a_1, b_1, c_1 > 0$,

Also the crisp value of triangular fuzzy number set $\tilde{A}_1$ can be determined by defuzzification which locates the Best Non-fuzzy Performance (BNP) value. Thus, the BNP values of fuzzy number are calculated by using the center of area (COA) method as follows: (Moeinzadeh and Hajfathaliha, 2010)

$$\text{BNP}_i = \frac{[(c-a)+(b-a)]}{3} + a, \qquad \forall_i, \quad (2.23)$$

**Definition 4:** A matrix $\tilde{\mathbf{D}}$ is called a fuzzy matrix if at least one element is a fuzzy number (Buckley, 1985).

### 2.5.3 Linguistic Variable

**Definition 1:** A linguistic variable is the variable whose values are not expressed in numbers but words or sentences in a natural or artificial language, i.e., in terms of linguistic (Zadeh, 1975). The concept of a linguistic variable is very useful in dealing with situations, which are too complex or not well defined to be reasonably described in conventional quantitative expressions (Zimmermann, 1991; Cheng and Lin, 2002; Kannan, 2008). For example, 'weight' is a linguistic variable whose values are 'very low', 'low', 'medium', 'high', 'very high', etc. Fuzzy numbers can also represent these linguistic values.

### 2.5.4 The Concept of Generalized Trapezoidal Fuzzy Numbers

By the definition given by (Chen, 1985), a generalized trapezoidal fuzzy number can be defined as $\tilde{A} = (a_1, a_2, a_3, a_4; w_{\tilde{A}})$, as shown in Fig. 2.4.

and the membership function $\mu_{\tilde{A}}(x): R \to [0,1]$ is defined as follows:

$$\mu_{\tilde{A}}(x) = \begin{cases} \dfrac{x-a_1}{a_2-a_1} \times w_{\tilde{A}}, & x \in (a_1, a_2) \\ w_{\tilde{A}}, & x \in (a_2, a_3) \\ \dfrac{x-a_4}{a_3-a_4} \times w_{\tilde{A}}, & x \in (a_3, a_4) \\ 0, & x \in (-\infty, a_1) \cup (a_4, \infty) \end{cases} \tag{2.24}$$

Here, $a_1 \leq a_2 \leq a_3 \leq a_4$ and $w_{\tilde{A}} \in [0,1]$

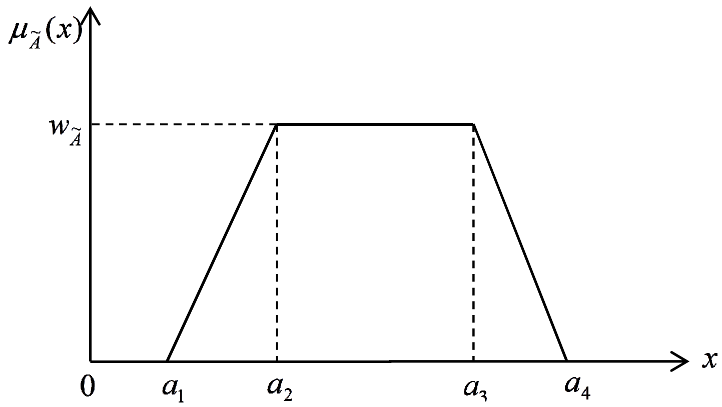


Fig. 2.4: Trapezoidal fuzzy number $\tilde{A}$

The elements of the generalized trapezoidal fuzzy numbers $x \in R$ are real numbers, and its membership function $\mu_{\tilde{A}}(x)$ is the regularly and continuous convex function, it shows that the membership degree to the fuzzy sets. If $-1 \le a_1 \le a_2 \le a_3 \le a_4 \le 1$, then $\tilde{A}$ is called the normalized trapezoidal fuzzy number. Especially, if $w_{\tilde{A}} = 1$, then $\tilde{A}$ is called trapezoidal fuzzy number $(a_1, a_2, a_3, a_4)$; if $a_1 < a_2 = a_3 < a_4$, then $\tilde{A}$ is reduced to a triangular fuzzy number. If $a_1 = a_2 = a_3 = a_4$, then $\tilde{A}$ is reduced to a real number.

Suppose that $\tilde{a} = (a_1, a_2, a_3, a_4; w_{\tilde{a}})$ and $\tilde{b} = (b_1, b_2, b_3, b_4; w_{\tilde{b}})$ are two generalized trapezoidal fuzzy numbers, then the operational rules of the generalized trapezoidal fuzzy numbers $\tilde{a}$ and $\tilde{b}$ are shown as follows (Chen and Chen, 2009):

$$\tilde{a} \oplus \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) \oplus (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$

$$(a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4; \min(w_{\tilde{a}}, w_{\tilde{b}})) \tag{2.25}$$

$$\tilde{a} - \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) - (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$

$$(a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1; \min(w_{\tilde{a}}, w_{\tilde{b}})) \tag{2.26}$$

$$\tilde{a} \otimes \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) \otimes (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$

$$(a, b, c, d; \min(w_{\tilde{a}}, w_{\tilde{b}})) \tag{2.27}$$

Here,

$$a = \min(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4)$$

$$b = \min(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3)$$

$$c = \max(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3)$$

$$d = \max(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4)$$

If $a_1, a_2, a_3, a_4, b_1, b_2, b_3, b_4$ are real numbers, then

$$\tilde{a} \otimes \tilde{b} = \left(a1 \times b1, a2 \times b2, a3 \times b3, a4 \times b4; \min\left(w_{\tilde{a}}, w_{\tilde{b}}\right)\right)$$

$$\tilde{a} / \tilde{b} = \left(a_1, a_2, a_3, a_4; w_{\tilde{a}}\right) \Big/ \left(b_1, b_2, b_3, b_4; w_{\tilde{b}}\right)$$

$$= \left(a_1 / b_4, a_2 / b_3, a_3 / b_2, a_4 / b_1; \min\left(w_{\tilde{a}}, w_{\tilde{b}}\right)\right) \tag{2.28}$$

Chen and Chen (2003) proposed the concept of COG point of generalized trapezoidal fuzzy numbers, and suppose that the COG point of the generalized trapezoidal fuzzy number $\tilde{a} = \left(a_1, a_2, a_3, a_4; w_{\tilde{a}}\right)$ is $\left(x_{\tilde{a}}, y_{\tilde{a}}\right)$, then:

$$y_{\tilde{a}} = \begin{cases} \dfrac{w_{\tilde{a}} \times \left(\dfrac{a_3 - a_2}{a_4 - a_1} + 2\right)}{6}, & if\ a_1 \neq a_4 \\ \dfrac{w_{\tilde{a}}}{2}, & if\ a_1 = a_4 \end{cases} \tag{2.29}$$

$$x_{\tilde{a}} = \frac{y_{\tilde{a}} \times \left(a_2 + a_3\right) + \left(a_1 + a_4\right) \times \left(w_{\tilde{a}} - y_{\tilde{a}}\right)}{2 \times w_{\tilde{a}}} \tag{2.30}$$

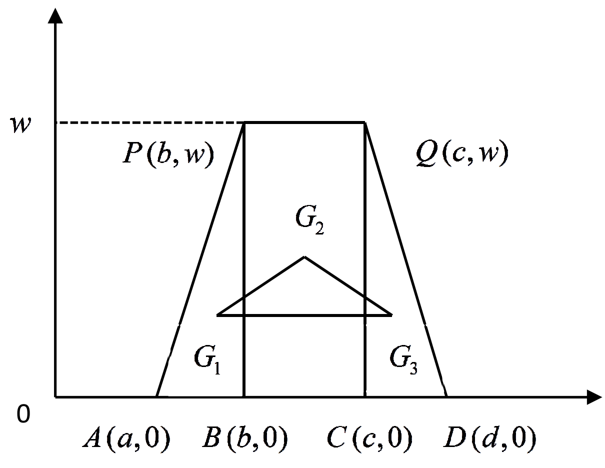


Fig. 2.5: Trapezoidal Fuzzy Number (Thorani et al., 2012)

### 2.5.5 Ranking of Generalized Trapezoidal Fuzzy Numbers

The centroid of a trapezoid is considered as the balancing point of the trapezoid (Fig. 2.5). Divide the trapezoid into three plane figures. These three plane figures are a triangle (APB), a rectangle (BPQC), and a triangle (CQD), respectively. Let the centroids of the three plane figures be $G_1$, $G_2$, and $G_3$ respectively (Thorani et al., 2012). The Incenter of these Centroids $G_1$, $G_2$ and $G_3$ is taken as the point of reference to define the ranking of generalized trapezoidal fuzzy numbers. The reason for selecting this point as a point of reference is that each centroid point are balancing points of each individual plane figure, and the Incentre of these Centroid points is a much more balancing point for a generalized trapezoidal fuzzy number. Therefore, this point would be a better reference point than the Centroid point of the trapezoid.

Consider a generalized trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$, (Fig. 2.5). The Centroids of the three plane figures are $G_1 = \left(\frac{a+2b}{3}, \frac{w}{3}\right)$, $G_2 = \left(\frac{b+c}{2}, \frac{w}{2}\right)$ and $G_3 = \left(\frac{2c+d}{3}, \frac{w}{3}\right)$ respectively.

Equation of the line $\overline{G_1G_3}$ is $y = \frac{w}{3}$ and $G_2$ does not lie on the line $\overline{G_1G_3}$. Therefore, $G_1G_2$ and $G_3$ are non-collinear and they form a triangle.

We define the Incentre $I_{\tilde{A}}(\bar{x}_0, \bar{y}_0)$ of the triangle with vertices $G_1$, $G_2$ and $G_3$ of the generalized trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$ as

$$I_{\tilde{A}}(\bar{x}_0, \bar{y}_0) = \left( \frac{\alpha\left(\frac{a+2b}{3}\right) + \beta\left(\frac{b+c}{2}\right) + \gamma\left(\frac{2c+d}{3}\right)}{\alpha+\beta+\gamma}, \frac{\alpha\left(\frac{w}{3}\right) + \beta\left(\frac{w}{2}\right) + \gamma\left(\frac{w}{3}\right)}{\alpha+\beta+\gamma} \right) \tag{2.31}$$

Here

$$\alpha = \frac{\sqrt{(c-3b+2d)^2 + w^2}}{6}$$

$$\beta = \frac{\sqrt{(2c+d-a-2b)^2}}{3}$$

$$\gamma = \frac{\sqrt{(3c-2a-b)^2 + w^2}}{6}$$

As a special case, for triangular fuzzy number $\tilde{A} = (a,b,c,d;w)$, i.e. $c = b$ the incentre of Centroids is given by

$$I_{\tilde{A}}(\bar{x}_0, \bar{y}_0) = \left( \frac{x\left(\frac{a+2b}{3}\right) + yb + z\left(\frac{2b+d}{3}\right)}{x+y+z}, \frac{x\left(\frac{w}{3}\right) + y\left(\frac{w}{2}\right) + z\left(\frac{w}{3}\right)}{x+y+z} \right) \tag{2.32}$$

Here

$$x = \frac{\sqrt{(2d-2b)^2 + w^2}}{6}$$

$$y = \frac{\sqrt{(d-a)^2}}{3}$$

$$z = \frac{\sqrt{(2b-2a)^2 + w^2}}{6}$$

The ranking function of the generalized trapezoidal fuzzy number $\tilde{A} = (a,b,c,d;w)$, which maps the set of all fuzzy numbers to a set of real numbers is denied as,

$$R(\tilde{A}) = x_0 \times y_0 = \left( \frac{x\left(\frac{a+2b}{3}\right) + yb + z\left(\frac{2b+d}{3}\right)}{x+y+z} \times \frac{x\left(\frac{w}{3}\right) + y\left(\frac{w}{2}\right) + z\left(\frac{w}{3}\right)}{x+y+z} \right) \tag{2.33}$$

This is the area between the incenter of the centroids $I_{\tilde{A}}(\bar{x}_0, \bar{y}_0)$ as denied in Eq. and the original point.

The Mode (m) of the generalized trapezoidal fuzzy number $\tilde{A} = (a,b,c,d;w)$, is defined as:

$$m = \frac{1}{2}\int_0^w (b+c)dx = \frac{w}{2}(b+c) \tag{2.34}$$

The Spread(s) of the generalized trapezoidal fuzzy number $\tilde{A} = (a,b,c,d;w)$, is defined as:

$$s = \int_0^w (d-a)dx = w(d-a) \tag{2.35}$$

The left spread $(ls)$ of the generalized trapezoidal fuzzy number $\tilde{A} = (a,b,c,d;w)$, is defined as:

$$ls = \int_0^w (b-a)dx = w(b-a) \tag{2.36}$$

The right spread $(rs)$ of the generalized trapezoidal fuzzy number $\tilde{A} = (a,b,c,d;w)$, is defined as:

$$rs = \int_0^w (d-c)dx = w(d-c) \tag{2.37}$$

Using the above definitions we now define the ranking procedure of two generalized trapezoidal fuzzy numbers.

Let $\tilde{A} = (a_1,b_1,c_1,d_1;w_1)$ and $\tilde{B} = (a_2,b_2,c_2,d_2;w_2)$ be two generalized trapezoidal fuzzy numbers. The working procedure to compare $\tilde{A}$ and $\tilde{B}$ is as follows:

**Step 1:** Find $R(\tilde{A})$ and $R(\tilde{B})$

Case (i) If $R(\tilde{A}) > R(\tilde{B})$ then $\tilde{A} > \tilde{B}$

Case (ii) If $R(\tilde{A}) < R(\tilde{B})$ then $\tilde{A} < \tilde{B}$

Case (iii) If If $R(\tilde{A}) = R(\tilde{B})$ comparison is not possible, then go to ***step 2***.

**Step 2:** Find $m(\tilde{A})$ and $m(\tilde{B})$

Case (i) If $m(\tilde{A}) > m(\tilde{B})$ then $\tilde{A} > \tilde{B}$

Case (ii) If $m(\tilde{A}) < m(\tilde{B})$ then $\tilde{A} < \tilde{B}$

Case (iii) If If $m(\tilde{A}) = m(\tilde{B})$ comparison is not possible, then go to ***step 3***.

**Step 3:** Find $s(\tilde{A})$ and $s(\tilde{B})$

Case (i) If $s(\tilde{A}) > s(\tilde{B})$ then $\tilde{A} < \tilde{B}$

Case (ii) If $s(\tilde{A}) < s(\tilde{B})$ then $\tilde{A} > \tilde{B}$

Case (iii) If If $s(\tilde{A}) = s(\tilde{B})$ comparison is not possible, then go to ***step 4***.

**Step 4:** Find $ls(\tilde{A})$ and $ls(\tilde{B})$

Case (i) If $ls(\tilde{A}) > ls(\tilde{B})$ then $\tilde{A} > \tilde{B}$

Case (ii) If $ls(\tilde{A}) < ls(\tilde{B})$ then $\tilde{A} < \tilde{B}$

Case (iii) If If $ls(\tilde{A}) = ls(\tilde{B})$ comparison is not possible, then go to ***step 5***.

**Step 5:** Examine $w_1$ and $w_2$

Case (i) If $w_1 > w_2$ then $\tilde{A} > \tilde{B}$

Case (ii) If $w_1 < w_2$ then $\tilde{A} < \tilde{B}$

Case (iii) If $w_1 = w_2$ then $\tilde{A} \approx \tilde{B}$

## 2.6 Empirical Data Analyses

The evaluation index system (appraisement platform) (hierarchy of key SCM performance metrics) platform adapted in this paper has been shown in Table 2.1 (Gunasekaran et al., 2001; Bhagwat and Sharma, 2007). The two-level hierarchical model consists of Level I and Level II performance indices. Strategic performance, Tactical performance and Operational performance have been considered at the Level I followed by Level II indices which encompass a number of supply chain performance metrics, under each of the Level I index. The definitions of various SC performance indices (as indicated in Table 2.1) have been furnished in the Appendix A (at the end of the dissertation).

An approach based on 'Modified Similarity Method' as proposed by (Safari et al., 2013) has been used to evaluate an overall SC performance index in relation to each of the candidate alternatives. Since most of the evaluation indices being subjective in nature; the aforesaid decision-making problem has been modified to work under fuzzy environment. In this context, the team of decision-makers' play an important role in providing decision information in relation to various SC performance indices (their weight as well as rating). In this study, the priority weights and corresponding appropriateness ratings (performance estimates) of individual SC performance indices have been expressed by linguistic variables collected from a decision-making group (experts). Linguistic information has been transformed into appropriate fuzzy number in accordance with a predefined fuzzy scale set by the decision-makers'. Based on the concept of 'Incentre of Centriods', provided by (Thorani et al., 2012) in fuzzy mathematics; fuzzy information (for appropriateness rating as well as priority weight for SC performance indices) has been converted into unique 'crisp score'. These crisp data have been utilized to determine overall SC performance extent and thereby, to facilitate SC performance benchmarking by using 'Modified Similarity Measure' approach. This method has been found considerably fruitful for solving multi-criteria decision making problem (MCDM) under uncertain environment.

In this empirical study, a decision-making problem has been formulated towards SC performance evaluation as well as benchmarking. In this problem, a number of candidate industries/enterprises (running under similar SC architecture) have been considered. The objective has been to compute SC performance index of the individual industry/enterprise and to derive performance ranking order of the same (Benchmarking). The procedural steps of performance evaluation framework have been explained below with detailed numerical illustrations.

**Step 1:** Constitution of SC performance appraisement platform and the expert panel. Assume that a committee of five decision-makers' (DMs) (DM1, DM2, DM3, DM4, DM5) has been formed which constitutes individuals of management practice as well as academia to participate in the decision-making process. The expert group has been instructed to finalize a performance appraisement platform (Table 2.1) in understanding with different performance measures as well as metrics after conducting several brainstorming sessions. Next, the appropriate linguistic scale has been selected in order to express DM's subjective preferences in assigning priority weight as well as appropriateness rating of individual SC performance indices. These linguistic data have been converted into fuzzy data as per the scales selected (Table 2.2-2.3).

**Step 2:** In the initial stage, the expert group has finalized priority importance (linguistic weights) in relation to each of the Level I as well as Level II performance indices (Table 2.4-2.5); which has been considered same for all the candidate alternatives.

**Step 3:** The expert group has then been instructed to visit candidate industries and put their linguistic judgment (opinion) in relation to ongoing performance of each SC performance indicator for the five alternative industries, as considered ($A_1$, $A_2$, $A_3$, $A_4$, $A_5$) (Table 2.6-2.10).

**Step 4:** Linguistic judgment has been further transformed into appropriate fuzzy number (as per the scales chosen; Table 2.2-2.3). Using 'fuzzy average rule', aggregated fuzzy weight (for individual Level II and Level I indices) as well as aggregated fuzzy rating (of individual Level II indices, for alternative enterprises) have been computed (Table 2.11-2.12 and Table 2.13). Using 'fuzzy weighted average rule', computed fuzzy ratings corresponding to individual Level I performance indices have been computed (Table 2.14).

Appropriateness rating for each of the Level I evaluation index $U_i$ (rating of $i_{th}$ index) has been computed as follows (Lin et al., 2006):

$$U_i = \frac{\sum U_{ij} \otimes w_{ij}}{\sum w_{ij}} \tag{2.38}$$

In this expression (Eq. 2.38) $U_{ij}$ has been denoted as aggregated appropriateness rating and aggregated fuzzy weights obtained (from Table 2.11) against $j_{th}$ index (at Level II) which is under $i_{th}$ index in the 1st level. Also $w_{ij}$ is the aggregated fuzzy weight against $j_{th}$ index (at Level II) which is under $i_{th}$ index at Level I.

**Step 5:** Then, develop a fuzzy multi-criteria group decision making (FMCGDM) matrix based on five alternatives and three main criterions/indices shown as in (Table 2.14). The aforesaid fuzzy-decision matrix (and corresponding fuzzy representation of the weight vector of Level I performance indices in Table 2.12) has been converted into 'crisp' representation by exploring the concept of 'Incentre of Centroids' of fuzzy numbers from fuzzy set theory (Thorani et al., 2012) (Table 2.15).

**Step 6:** Normalize the crisp decision matrix by using Eq. (2.4). The normalized value $x_{ij}^{'}$ furnished in Table 2.16.

**Step 7:** Evaluate weighted normalized decision matrix by using Eq. (2.6). The weighted normalized $y_{ij}^{'}$ values have been shown in Table 2.17.

**Step 10:** Then according to the 'Modified Similarity Measure Approach' the degree of conflict for the alternatives have been evaluated; based on that appropriate ranking order of five alternatives has thus been determined. The result has been furnished in Table 2.18.

**Step 11:** Table 2.19 exhibits comparative analysis of the result obtained by modified similarity measure approach to that of TOPSIS. The ranking order appears to be the same for both the case.

As per the analysis it has been found that the second alternative ($A_2$) appeared as best ranked amongst the five possible alternatives. With respect to Table 2.18, it can be seen that the vector relating second alternative ($A_2$) has angular size 0 degrees (cos1) with the positive ideal solution and 6.78 degrees (cos0.993) with the negative ideal solution. Therefore, this alternative has the highest similarity to the positive ideal and the lowest similarity to the negative ideal solution compared with other options and it is fully in accordance with the main concept of the aforesaid method. It can be seen that this method can provide reliable results and be treated as one of the Multi-Criteria Decision Making (MCDM) techniques. Consequently, this multi-criteria analysis method is of practical use in solving real life multi-criteria analysis decision problems.

Procedural steps of the aforesaid performance appraisement module have been briefly summarized below.

1. Selection of an integrated criteria-hierarchy: an evaluation index system consisting of SC performance indicators (criterions) at different levels.

2. Selection of a group of decision-makers (experts).

3. Selection of an appropriate linguistic scale based on which experts can express their personal judgment in relation to priority importance as well as performance extent of individual evaluation indices at different levels of the criteria-hierarchy considered.

4. Fuzzy transformation of expert judgment (expressed in linguistic terminology) based on a suitable fuzzy scale.

5. Based on fuzzy arithmetic operational rules aggregated fuzzy performance rating of individual performance indices (at highest level) and aggregated fuzzy weight of individual evaluation indices at different levels are to be computed.

6. Based on fuzzy weighted average rule, computed fuzzy performance ratings of individual evaluation indices (at Level I) are computed. This treatment reduces an integrated criteria hierarchy (multi-level) into a list of main criterions (at Level I).

7. Representation of a multi-criteria decision matrix in which all data are expressed in fuzzy numbers. This matrix represents criteria values (fuzzy) for a set of criterions (Level I) corresponding to a set of candidate alternatives.

8. Using the concept of 'Incentre of Centroid' in fuzzy set theory; the crisp representations of individual fuzzy data in relation to the aforementioned decision matrix are computed.

9. The crisp weight of individual performance indices (at Level I) are computed using the said concept of 'Incentre of Centroid'.

10. Normalization of decision making matrix (all data are expressed in crisp numbers).

11. Derivation of weighted normalized decision matrix.

12. Exploration of modified version of Deng's similarity measure approach to derive appropriate ranking order of candidate alternatives. Alternatives are nothing but candidate

industries/enterprises running under similar SC architecture. Our objective is to select the best alternative in view of the ongoing SC performance extent.

## 2.7 Managerial Implications: Practical Relevance

Supply chain management has become increasingly important to businesses which supply goods and services to the end customers (Waller, 2003). Supply chain management is a multi-disciplinary topic of immense potential in modern business management and research. It enhances organizational productivity and profitability through a revolutionary philosophy to managing the business with sustained competitiveness (Gunasekaran et al., 2004).

In the competitive marketplace achieving sustainable supply chains is an issue that is still to be solved despite its relevance. For that reason, there are several tools and techniques that have been focused in the literature in order to aid and support supply chain sustainability. Performance measurement frameworks are useful tools that facilitate to collect and monitor the evolution of performance of any organization. However, there are few performance measurement frameworks developed in the literature for that purpose, all of them recently published, and lacking of a solid structure that aids to define and implement performance measurement elements in a way that provide an overall evaluation of the sustainability status of the supply chain (Verdecho et al. (2012). In view of this, aforesaid work attempts to conceptualize a novel performance measurement framework to fill this research gap.

The aforesaid study bears significant contribution from managerial point of view. It provides a ready test-kit to assess ongoing performance extent of the organizational SC; to compare with the desired performance level; and, to rank different enterprises with respect to their overall SC performance extent (Performance Benchmarking). Benchmarking can help an industry to set or alter SC strategies; best practices can be identified as well. Enterprises can follow their peers (consequently benchmarked practices) in order to improve their level of performance in relation the concerned supply chain network entities.

## 2.8 Concluding Remarks

The foregoing research utilized fuzzy set theory in combination with the modified version of Deng's similarity measure approach towards SC performance appraisement as well as benchmarking.

The contribution of this work has been summarized below.

1. Adaptation of a 2-Level criteria hierarchy for SC performance evaluation.

2. Exploration of fuzzy logic to overcome vagueness, incompleteness as well as inconsistency of evaluation information due to subjectivity of performance criterions/indices.

3. Adaptation of the concept of ‘Incentre of Centroids’ method available in fuzzy theory towards crisp representation of fuzzy evaluation inform.

4. Exploration of modified version of Deng’s similarity measure approach towards estimating overall SC performance index $\left(P_i\right)$.

5. Benchmarking of alternative industries/enterprises running under similar SC structure.

Table 2.1: A list of Key SCM Performance metrics

| Level I (Performance indices) | Level II (Performance indices) | References/ Citations |
|---|---|---|
| Strategic performance, $C_1$ | Total cash flow time, $C_{11}$ | Stewart (1995) |
| | Rate of return on investment, $C_{12}$ | Christopher (1992); Dobler and Burt (1996) |
| | Flexibility to meet particular customer needs, $C_{13}$ | Bower and Hout (1988); Christopher (1992) |
| | Delivery lead time, $C_{14}$ | Rushton and Oxley (1991); Christopher (1992) |
| | Total cycle time, $C_{15}$ | Christopher (1992); Stewart (1995) |
| | Buyer-supplier partnership level, $C_{16}$ | Toni et al. (1994) |
| | Customer query time, $C_{17}$ | Mason-Jones and Towill (1997) |
| Tactical performance, $C_2$ | Extent of cooperation to improve quality, $C_{21}$ | Graham et al. (1994) |
| | Total transportation cost, $C_{22}$ | Rushton and Oxley (1991) |
| | Truthfulness of demand, $C_{23}$ | Fisher (1997); Harrington (1996) |
| | Predictability/forecasting methods, $C_{24}$ | (Gunasekaran et al., 2001) |
| | Product development cycle time, $C_{25}$ | Bower and Hout (1988) |
| Operational performance, $C_3$ | Manufacturing cost, $C_{31}$ | Wild (1995) |
| | Capacity utilization, $C_{32}$ | Stewart (1995) |
| | Information carrying cost, $C_{33}$ | Levy (1997); Lee and Billington (1992) |
| | Inventory carrying cost, $C_{34}$ | Stewart (1995); Dobler and Burt (1996); Slack et al. (1998); Pyke and Cohen (1994) |

Table 2.2: Linguistic variables for importance of each criterion

| Linguistic data | Triangular fuzzy number (TFN) |
|---|---|
| Very Low (VL) | (0, 0.2, 0.5) |
| Low (L) | (0.2, 0.4, 0.5) |
| Medium (M) | (0.4, 0.6, 0.8) |
| High (H) | (0.6, 0.8, 1.0) |
| Very High (VH) | (0.8, 0.9, 1.0) |

Table 2.3: Linguistic variables for rating of each alternative

| Linguistic data | Triangular fuzzy number (TFN) |
|---|---|
| Very Poor (VP) | (0, 0, 1) |
| Poor (P) | (0, 1, 3) |
| Medium Poor (MP) | (1, 3, 5) |
| Fair (F) | (3, 5, 7) |
| Medium Good (MG) | (5, 7, 9) |
| Good (G) | (7, 9, 10) |
| Very Good (VG) | (9, 10, 10) |

Table 2.4: Priority weight (Level II) given by the Decision-Makers

| Performance metrics | Priority weights (Linguistic Term) | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | H | H | H | H | H |
| $C_{12}$ | H | H | H | VH | VH |
| $C_{13}$ | VH | H | VH | H | VH |
| $C_{14}$ | M | H | H | H | H |
| $C_{15}$ | M | H | M | H | M |
| $C_{16}$ | VH | H | VH | VH | VH |
| $C_{17}$ | H | H | VH | VH | VH |
| $C_{21}$ | M | H | VH | H | H |
| $C_{22}$ | H | H | H | VH | H |
| $C_{23}$ | VH | VH | VH | H | H |
| $C_{24}$ | H | VH | H | VH | H |
| $C_{25}$ | H | H | H | H | H |
| $C_{31}$ | VH | H | VH | H | H |
| $C_{32}$ | H | H | H | VH | H |
| $C_{33}$ | H | VH | VH | VH | H |
| $C_{34}$ | H | H | H | H | H |

Table 2.5: Priority weight (Level I) given by the Decision-Makers

| Level I | Priority weights (Linguistic Term) | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_1$ | H | H | H | VH | H |
| $C_2$ | VH | H | H | VH | H |
| $C_3$ | VH | VH | H | H | H |

Table 2.6: Appropriateness rating (Level II) given by the Decision-Makers **(Alternative 1)**

| Performance metrics | Appropriateness rating (Linguistic Term) | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | F | F | MG | MG | MG |
| $C_{12}$ | F | F | F | F | F |
| $C_{13}$ | MG | MG | G | G | G |
| $C_{14}$ | MG | G | G | G | G |
| $C_{15}$ | MP | P | F | F | F |
| $C_{16}$ | F | F | F | F | F |
| $C_{17}$ | P | P | MP | F | F |
| $C_{21}$ | F | F | F | F | F |
| $C_{22}$ | MG | G | G | MG | MG |
| $C_{23}$ | F | MG | F | F | MG |
| $C_{24}$ | F | F | MG | F | F |
| $C_{25}$ | G | G | G | MG | G |
| $C_{31}$ | G | MG | G | MG | G |
| $C_{32}$ | MG | F | F | F | F |
| $C_{33}$ | G | G | MG | G | G |
| $C_{34}$ | F | F | F | F | MG |

Table 2.7: Appropriateness rating (Level II) given by the Decision-Makers **(Alternative 2)**

| Performance metrics | Appropriateness rating (Linguistic Term) | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | MG | G | G | G | G |
| $C_{12}$ | G | MG | MG | G | MG |
| $C_{13}$ | VG | VG | G | G | VG |
| $C_{14}$ | G | VG | G | VG | VG |
| $C_{15}$ | MG | MG | G | MG | VG |
| $C_{16}$ | G | G | G | G | G |
| $C_{17}$ | VG | VG | G | G | VG |
| $C_{21}$ | G | G | G | G | VG |
| $C_{22}$ | MG | MG | MG | G | G |
| $C_{23}$ | VG | G | G | G | VG |
| $C_{24}$ | G | VG | G | VG | G |
| $C_{25}$ | VG | VG | VG | VG | VG |
| $C_{31}$ | G | G | G | VG | G |
| $C_{32}$ | MG | MG | MG | G | G |
| $C_{33}$ | G | G | G | VG | G |
| $C_{34}$ | VG | VG | G | VG | G |

Table 2.8: Appropriateness rating (Level II) given by the Decision-Makers **(Alternative 3)**

| Performance metrics | Appropriateness rating (Linguistic Term) | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | G | MG | MG | G | G |
| $C_{12}$ | G | G | MG | G | G |
| $C_{13}$ | MG | VG | G | G | G |
| $C_{14}$ | G | VG | G | VG | G |
| $C_{15}$ | G | MG | G | MG | G |
| $C_{16}$ | G | G | G | G | G |
| $C_{17}$ | G | VG | G | G | VG |
| $C_{21}$ | G | G | G | G | G |
| $C_{22}$ | G | MG | MG | G | G |
| $C_{23}$ | MG | G | G | G | G |
| $C_{24}$ | G | VG | G | G | G |
| $C_{25}$ | MG | VG | VG | G | G |
| $C_{31}$ | G | G | G | G | G |
| $C_{32}$ | G | MG | MG | G | MG |
| $C_{33}$ | G | G | G | G | MG |
| $C_{34}$ | G | VG | G | G | MG |

Table 2.9: Appropriateness rating (Level II) given by the Decision-Makers **(Alternative 4)**

| Performance metrics | Appropriateness rating (Linguistic Term) | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | F | F | MP | MP | MP |
| $C_{12}$ | F | F | F | F | MG |
| $C_{13}$ | MG | F | F | F | F |
| $C_{14}$ | MP | F | F | MP | MP |
| $C_{15}$ | MP | MP | MP | MP | MP |
| $C_{16}$ | P | MP | P | P | P |
| $C_{17}$ | F | F | F | MG | F |
| $C_{21}$ | MG | MG | MG | MG | MG |
| $C_{22}$ | F | MP | F | MP | MP |
| $C_{23}$ | MG | MG | F | MG | MG |
| $C_{24}$ | F | MG | MG | MG | MG |
| $C_{25}$ | G | MG | G | MG | MG |
| $C_{31}$ | F | MG | F | F | F |
| $C_{32}$ | MG | MG | MG | F | MG |
| $C_{33}$ | F | F | F | F | F |
| $C_{34}$ | MG | MG | F | MG | F |

Table 2.10: Appropriateness rating (Level II) given by the Decision-Makers **(Alternative 5)**

| Performance metrics | Appropriateness rating (Linguistic Term) | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | MG | VG | G | G | G |
| $C_{12}$ | G | VG | G | VG | G |
| $C_{13}$ | G | MG | G | MG | G |
| $C_{14}$ | G | G | G | G | G |
| $C_{15}$ | G | VG | G | G | VG |
| $C_{16}$ | G | G | G | G | G |
| $C_{17}$ | MG | MG | F | MG | MG |
| $C_{21}$ | F | MG | MG | MG | MG |
| $C_{22}$ | G | MG | G | MG | MG |
| $C_{23}$ | F | MG | F | F | F |
| $C_{24}$ | MG | MG | MG | F | MG |
| $C_{25}$ | G | MG | G | MG | G |
| $C_{31}$ | G | G | G | G | G |
| $C_{32}$ | G | VG | G | G | VG |
| $C_{33}$ | G | G | G | G | G |
| $C_{34}$ | MG | MG | F | MG | MG |

Table 2.11: Aggregated Fuzzy Priority weight for individual indices at Level II

| Level II indices | Aggregated fuzzy priority weight |
|---|---|
| $C_{11}$ | (0.600,0.800,1.000) |
| $C_{12}$ | (0.680,0.840,1.000) |
| $C_{13}$ | (0.720,0.860,1.000) |
| $C_{14}$ | (0.560,0.760,0.960) |
| $C_{15}$ | (0.480,0.680,0.880) |
| $C_{16}$ | (0.760,0.880,1.000) |
| $C_{17}$ | (0.720,0.860,1.000) |
| $C_{21}$ | (0.600,0.780,0.960) |
| $C_{22}$ | (0.640,0.820,1.000) |
| $C_{23}$ | (0.720,0.860,1.000) |
| $C_{24}$ | (0.680,0.840,1.000) |
| $C_{25}$ | (0.600,0.800,1.000) |
| $C_{31}$ | (0.680,0.840,1.000) |
| $C_{32}$ | (0.640,0.820,1.000) |
| $C_{33}$ | (0.720,0.860,1.000) |
| $C_{34}$ | (0.600,0.800,1.000) |

Table 2.12: Aggregated Fuzzy Priority weight for individual indices at Level I

| Level I indices | Aggregated fuzzy priority weight |
|---|---|
| $C_1$ | (0.60,0.78,0.96) |
| $C_2$ | (0.68,0.84,1.00) |
| $C_3$ | (0.68,0.84,1.00) |

Table 2.13: Fuzzy aggregated appropriateness rating of Level II indices (for alternatives $A_1$ to $A_5$)

| Level II indices | Fuzzy aggregated appropriateness rating of Level II indices (for alternatives $A_1$ to $A_5$) | | | | |
|---|---|---|---|---|---|
| | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ |
| $C_{11}$ | (3.60, 6.20, 8.20) | (6.60, 8.60, 9.80) | (6.20, 8.20, 9.60) | (1.80, 3.80, 5.80) | (7.60, 8.80, 9.80) |
| $C_{12}$ | (3.00, 5.00, 7.00) | (7.20, 7.80, 9.40) | (6.60, 8.60, 9.80) | (3.40, 5.40, 7.40) | (7.80, 9.40, 10.0) |
| $C_{13}$ | (6.20, 8.20, 9.60) | (8.20, 9.60, 10.00) | (7.60, 8.80, 9.80) | (3.40, 5.40, 7.40) | (6.20, 8.20, 9.60) |
| $C_{14}$ | (6.60, 8.60, 9.80) | (8.20, 9.60, 10.00) | (7.80, 9.40, 10.0) | (1.80, 3.80, 5.80) | (7.00, 9.00, 10.0) |
| $C_{15}$ | (2.00, 3.80, 5.80) | (6.20, 8.00, 9.40) | (6.20, 8.20, 9.60) | (1.00, 3.00, 5.00) | (7.80, 9.40, 10.0) |
| $C_{16}$ | (3.00, 5.00, 7.00) | (7.00, 9.00, 10.00) | (7.00, 9.00, 10.0) | (0.20, 1.40, 3.40) | (7.00, 9.00, 10.0) |
| $C_{17}$ | (1.40, 3.00, 5.00) | (8.20, 9.60, 10.00) | (7.80, 9.40, 10.0) | (3.40, 5.40, 7.40) | (1.40, 3.40, 5.40) |
| $C_{21}$ | (3.00, 5.00, 7.00) | (7.40, 9.20, 10.00) | (7.00, 9.00, 10.0) | (5.00, 7.00, 9.00) | (1.40, 3.40, 5.40) |
| $C_{22}$ | (7.20, 7.80, 9.40) | (7.20, 7.80, 9.00) | (6.20, 8.20, 9.60) | (1.80, 3.80, 5.80) | (7.20, 7.80, 9.40) |
| $C_{23}$ | (5.00, 5.80, 7.80) | (7.80, 9.40, 10.00) | (6.60, 8.60, 9.80) | (1.40, 3.40, 5.40) | (3.40, 5.40, 7.40) |
| $C_{24}$ | (3.40, 5.40, 7.40) | (7.80, 9.40, 10.00) | (7.40, 9.20, 10.0) | (4.60, 6.60, 8.60) | (1.40, 3.40, 5.40) |
| $C_{25}$ | (6.60, 8.60, 9.80) | (9.00, 10.00, 10.0) | (7.40, 9.00, 9.80) | (7.20, 7.80, 9.40) | (6.20, 8.20, 9.60) |
| $C_{31}$ | (6.20, 8.20, 9.60) | (7.40, 9.20, 10.00) | (7.00, 9.00, 10.0) | (3.40, 5.40, 7.40) | (7.00, 9.00, 10.0) |
| $C_{32}$ | (3.40, 5.40, 7.40) | (7.20, 7.00, 9.40) | (7.20, 7.80, 9.40) | (1.40, 3.40, 5.40) | (7.80, 9.40, 10.0) |
| $C_{33}$ | (6.60, 8.60, 9.80) | (7.40, 9.00, 10.00) | (6.60, 8.60, 9.80) | (3.00, 5.00, 7.00) | (7.00, 9.00, 10.0) |
| $C_{34}$ | (3.40, 5.40, 7.40) | (8.20, 9.60, 10.00) | (7.60, 8.80, 9.80) | (4.20, 6.20, 8.20) | (1.40, 3.40, 5.40) |

Table 2.14: Computed performance rating of Level I indices (for alternatives $A_1$ to $A_5$)

| Level I indices | Fuzzy aggregated appropriateness rating of Level II indices (for alternatives $A_1$ to $A_5$) | | | | |
|---|---|---|---|---|---|
| | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ |
| $C_1$ | (2.43,5.69, 11.35) | (4.91, 8.91, 14.84) | (5.47, 8.82, 14.88) | (1.45, 4.05, 9.15) | (4.14, 8.11, 13.98) |
| $C_2$ | (3.28,6.51, 12.69) | (5.12, 9.16, 15.12) | (4.52, 8.79, 15.06) | (2.54, 5.68, 11.7) | (2.53, 5.64, 11.42) |
| $C_3$ | (3.30,6.94, 12.95) | (4.97, 8.96, 14.92) | (4.67, 8.55, 14.77) | (1.97, 4.99, 10.6) | (3.91, 7.75, 13.41) |

Table 2.15: Crisp representation of decision making matrix and corresponding crisp weight

| Level I indices | Crisp weight | Appropriateness rating (crisp scope) of Level II indices (for alternatives $A_1$ to $A_5$) | | | | |
|---|---|---|---|---|---|---|
| | | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ |
| $C_1$ | 0.291 | 2.360 | 3.682 | 3.658 | 1.682 | 3.364 |
| $C_2$ | 0.311 | 2.702 | 3.789 | 3.650 | 2.357 | 2.339 |
| $C_3$ | 0.311 | 2.878 | 3.700 | 3.548 | 2.073 | 3.215 |

Table 2.16: Normalized Decision Matrix

| Alternatives | Criteria | | |
|---|---|---|---|
| | $C_1$ | $C_2$ | $C_3$ |
| $A_1$ | 0.346 | 0.398 | 0.410 |
| $A_2$ | 0.539 | 0.559 | 0.527 |
| $A_3$ | 0.535 | 0.538 | 0.506 |
| $A_4$ | 0.246 | 0.347 | 0.296 |
| $A_5$ | 0.493 | 0.345 | 0.458 |

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Table 2.17: Weighted Normalized Decision Matrix

| Alternatives | Criteria | | |
|---|---|---|---|
| | $C_1$ | $C_2$ | $C_3$ |
| $A_1$ | 0.101 | 0.124 | 0.128 |
| $A_2$ | 0.157 | 0.174 | 0.164 |
| $A_3$ | 0.156 | 0.167 | 0.157 |
| $A_4$ | 0.072 | 0.108 | 0.092 |
| $A_5$ | 0.143 | 0.107 | 0.143 |

Table 2.18: The values of $S^+, S^-, P_i$ for all alternatives

| Alternatives | $C_1$ | $C_2$ | $C_3$ | $\text{Cos}\theta_i^+$ | $\text{Cos}\theta_i^-$ | $S^+$ | $S^-$ | P | Ranking order |
|---|---|---|---|---|---|---|---|---|---|
| $A_1$ | 2.360 | 2.702 | 2.878 | 0.997 | 0.996 | 0.711 | 0.775 | 0.478 | 4 |
| $A_2$ | 3.682 | 3.789 | 3.700 | 1.000 | 0.993 | 1.000 | 0.554 | 0.643 | 1 |
| $A_3$ | 3.658 | 3.650 | 3.548 | 1.000 | 0.991 | 0.972 | 0.571 | 0.630 | 2 |
| $A_4$ | 1.682 | 2.357 | 2.073 | 0.992 | 1.000 | 0.548 | 0.997 | 0.355 | 5 |
| $A_5$ | 3.364 | 2.339 | 3.215 | 0.987 | 0.963 | 0.797 | 0.708 | 0.529 | 3 |
| $A^{*+}$ | 3.682 | 3.789 | 3.7 | ($A^{*+}$ and $A^{*-}$ are Ideal values) | | | | | |
| $A^{*-}$ | 1.682 | 2.339 | 2.073 | | | | | | |

Table 2.19: Comparison of the TOPSIS method and Modified Similarity Method

| Alternatives | TOPSIS Method | | Modified Similarity Method | |
|---|---|---|---|---|
| | $C_i$ | Ranking order | $P_i$ | Ranking order |
| $A_1$ | 0.032 | 4 | 0.478 | 4 |
| $A_2$ | 0.084 | 1 | 0.643 | 1 |
| $A_3$ | 0.080 | 2 | 0.630 | 2 |
| $A_4$ | 0.001 | 5 | 0.355 | 5 |
| $A_5$ | 0.058 | 3 | 0.529 | 3 |

Table 2.20: Comparing working principles of TOPSIS and Modified Similarity Measure Approach

| TOPSIS (Cohon, 1978) | Modified Similarity Approach |
|---|---|
| $C_i = \frac{D_i^-}{D_i^- + D_i^+}$ | $P_i = \frac{S_i^+}{S_i^+ + S_i^-}$ |
| $A_i = A^+, D^+ = 0, C_i = 1$ | $A_i = A^+, S^+ = 1, P_i = \frac{1}{1 + S_i^-}$ |
| $A_i = A^+, D^+ = 0, C_i = 1$ | $A_i = A^-, S^- = 1, P_i = \frac{S_i^+}{1 + S_i^+}$ |
| $0 \le C_i \le 1$ | |
| $D_i^+ =$ Euclidean distance between $A_i$ and $A^+$<br>$D_i^- =$ Euclidean distance between $A_i$ and $A^-$ | $0 < P_i < 1$<br>$0 \le \theta < 90^0$ |

# CHAPTER 3

## Supply Chain Performance Assessment in Fuzzy Context

## 3.1 Overview

In today's competitive global marketplace, Supply Chain Management (SCM) has become a key strategic consideration towards achieving organizational goals such as enhanced competitiveness in terms of productivity, better customer care and increased profitability. In recent years, supply chain performance measurement and metrics have received much attention from researchers as well as management practitioners. Performance evaluation of supply chain provides important strategic guidelines for the effective and economic implementation of supply chain management. In literature, there is mention of dearth of research for better understanding of supply chain performance. The deficiencies in the existing approaches are as follows:

1. Lack of logical construct consisting of capabilities-attributes as well as criterions (integrated criteria hierarchy) to describe supply chain performance extent in industrial perspectives (SC).
2. Subjective assessment of performance (in relation to industrial SC) is generally vague in nature.
3. Lack of systematic framework (mathematic base) to quantify overall supply chain performance extent (quantitative metric).
4. Supply chain performance appraisement from Decision-Makers (DMs) viewpoint.
5. Lack of understanding on present scenario (status) of SCM in Indian industries.

To this end, this paper aims at addressing the dearth of research for better understanding of supply chain performance metrics followed by development of effective Decision Support Systems (DSS) towards supply chain performance appraisement by exploring the concept of Fuzzy Logic. The proposed frameworks may help management practitioners to appraise existing performance extent that are suitable for certain organizational supply chain context at which a company operates, as well as to compare SC performance extent of different industries operating under similar SC architecture; and to select the best one (performance benchmarking). The research has been extended to identify ill-performing areas of the entire organizational supply chain.

## 3.2 Introduction and Research Background

Supply chain management has become such a popular topic in modern business management and researches. It brings the revolutionary philosophy and approach to manage the business with the sustained competitiveness (Kamalabadi et al., 2008). It integrates the components of supply chain in a holistic manner (Zarandi et al., 2007).

In today's global market, supply chain management (SCM) is being viewed as a key strategic factor for increasing organizational effectiveness and for better realization of organizational goals such as enhanced competitiveness, better customer care and increased profitability (Gunasekaran et al., 2001). In recent years, organizational performance measurement and metrics have received much attention from researchers and practitioners. The role of these measures and metrics in the success of an organization cannot be overstated because they affect strategic, tactical and operational planning and control. Performance measurement and metrics have an important role to play in setting objectives, evaluating performance, and determining future courses of actions (Gunasekaran et al. 2004). However, the existing performance measurement theory fails to provide its necessary support in strategy development, decision making and performance improvement (Kamalabadi et al., 2008).

Beamon (1999) focused on the performance measures used in supply chain models by considering three types of performance measures: resource measures, output measures, and flexibility measures. Gunasekaran et al. (2001) developed a framework for measuring the strategic, tactical and operational level performance in a supply chain. The author emphasized on the performance measures dealing with suppliers, delivery performance, customer-service, and inventory and logistics costs in a SCM. Chan (2003) presented the formulization of both quantitative and qualitative performance measurements for easy representation and clear understanding of supply chain management. Apart from the common criteria such as cost and quality, five other performance measurements were defined: resource utilization; flexibility; visibility; trust; and innovativeness. In addition, a multi-attribute decision-making technique, an analytic hierarchy process (AHP), was used to make decisions based on the priority of the said performance measures.

Kleijnen and Smits (2003) attempted to deal with multiple metrics in SCM via the balanced scorecard, which measured customers, internal processes, innovations, and finance. This paper distinguished four simulation types for SCM: (i) spreadsheet simulation, (ii) system dynamics, (iii) discrete-event simulation, and (iv) business games. Perona and Miragliotta (2004) performed an empirical research to investigate how complexity could affect a manufacturing company's performances, and those of its supply chain which an emphasis to sales, inbound and outbound logistics, product and process engineering, production and organizational issues.

Agarwal and Shankar (2005) proposed a System Dynamics-based model in order to understand the dynamic behavior of the variables that could play a major role in the performance improvement in a supply chain. The model provided an effective framework for analyzing different variables affecting supply chain performance. Variables emanating from performance measures such as gaps in customer satisfaction, cost minimization, lead-time reduction, service level improvement and quality improvement were identified as goal-seeking loops. Bhagwat and Sharma (2007) developed a balanced scorecard for supply chain management (SCM) capable of measuring and evaluating day-to-day business operations from following four perspectives: finance, customer, internal business process, and learning and growth. Aramyan et al. (2007) aimed to evaluate the usefulness of a novel conceptual model for supply chain performance measurement in an agri-food supply chain. A conceptual model for integrated supply chain performance measurement was evaluated in a Dutch-German tomato supply chain. From the case study, four main categories of performance measures (i.e. efficiency, flexibility, responsiveness, and food quality) were identified as key performance components of the tomato supply chain performance measurement system.

Zarandi et al. (2007) concentrated on supply chain system modeling with fuzzy linear programming, and fuzzy expert system for an automobile plant. Kamalabadi et al. (2008) presented a FMADM (Fuzzy Multi Attribute Decision Making) method to supply chain performance measurement. Ho et al. (2008) developed a genetic algorithm (GA)-based process knowledge integration system (GA-PKIS) for generalizing a set of nearly optimal fuzzy rules in quality enhancement based on the extracted fuzzy association rules in a supply chain network. Cai et al. (2009) proposed a framework to improve the iterative key performance indicators (KPIs) accomplishment in a supply chain context. The proposed framework quantitatively analyzed the interdependent relationships amongst a set of KPIs. It could identify crucial KPI accomplishment costs and proposed performance improvement strategies for decision-makers in a supply chain. Tao (2009) constructed a performance evaluation index system of supply chain by combining improved entropy method and fuzzy matter-element theory to establish a fuzzy-matter model for evaluating supply chain performance. Papakiriakopoulos and Pramatari, (2010) demonstrated the challenges when developing a common performance measurement system (PMS) in the context of a collaborative supply chain.

Trkman et al. (2010) investigated the relationship between analytical capabilities in the plan, source, make and deliver area of the supply chain and its performance using information system support and business process orientation as moderators. Structural equation modeling employed a sample of different companies from different industries from the USA, Europe, Canada, Brazil and China. The findings suggested the existence of a statistically significant relationship between analytical capabilities and performance. The moderation effect of information systems support was found considerably stronger than the effect of business process orientation.

Bindu and Ahuja (2010) proposed an innovative cross-boundary performance measurement method from a supply chain system perspective. Fuzzy set theory was introduced to address the real situation in the judgment and evaluation processes. Chen et al. (2011) focused on supply chain performance evaluation of the wafer testing house in Taiwan. This investigation applied the Fuzzy Analytic Hierarchy Process (FAHP) to derive the weights of influential indicators for evaluating the supply chain performance and the Grey Relation Analysis (GRA) was used to evaluate the performance between the Free Cross-Strait Market (FCSM) and E-Commerce (EC) aspects.

Rao et al. (2011) focused on a case study conducted in a leading batteries manufacturing firm in South India and conducted analysis of elemental performances in overall delivery performance of an entire supply chain by an integrated approach. Nonlinear Programming and Dynamic Programming models were used to get optimal and sub-optimal solutions to help firms in benchmarking expected performance levels. Erkan and Baç (2011) focused on The Supply Chain Operations Reference model (SCOR), a management tool used to address, improve, and communicate supply chain management decisions within a company and with suppliers and customers of a company. Banomyong and Supatn (2011) presented a supply chain performance assessment tool that measured the performance of key supply chain activities of a firm under different performance dimensions based on three dimensions: cost, time, and reliability. The tool was pilot-tested on different local Small and medium enterprises (SMEs) in Thailand.

Ip et al. (2011) proposed an integrated approach towards modeling and measuring supply chain performance and stability using system dynamics (SD) and the autoregressive integrated moving average (ARIMA). It has been found that effectiveness and efficiency, with six corresponding indicators (product reliability, employee fulfillment, customer fulfillment, on-time delivery, profit growth, and working efficiency), seemed to be the most significant factors in the performance of the supply chain. Baç and Erkan (2011) proposed a mathematical model to evaluate supply chain performance using some key performance indicators. This model could be used to evaluate the flexibility characteristics of logistic, market, supplier, machine, labor, information system, and routing of the supply chain.

Ganga and Carpinetti (2011) proposed a supply chain performance evaluation model based on fuzzy logic to predict performance based on causal relationships between metrics of the Supply Council Operations Reference model (SCOR) model. Fuzzy logic was found a technique suitable for dealing with uncertainty and subjectivity, which was found as an interesting auxiliary approach to manage performance of supply chains. El-Baz (2011) reported a fuzzy decision making approach to deal with the performance measurement in supply chain systems based on fuzzy set theory and the pair-wise comparison of Analytical Hierarchy Process (AHP), which ensured the consistency of the designer's assignments of importance of one factor over another to find the weight of each of the manufacturing activity in the departmental organization.

Uysal (2012) applied the Decision Making Trial and Evaluation Laboratory (DEMATEL) Method to deal with the importance and causal relationships between the sustainable supply chain performance measurements criteria by considering the interrelationships among them. In order to analyze the above-mentioned graph structure, a multi-criteria decision making methods of graph theory and matrix approach were used.

Supply chain management has appeared such a serious topic in modern business management today. It brings the revolutionary philosophy and approach to manage the business effectively and efficiently with the sustained competitiveness. However, the existing performance measurement theory fails to provide its necessary support in strategy development, decision making and performance improvement (Kamalabadi et al., 2008). To this end, present work attempts to introduce different performance appraisement forums (evaluation index system) in order to evaluate existing performance of the organizational supply chain; in a logical as well as systematic way. The proposed appraisement modules may help the industries for continuous monitoring of supply chain performance; it can identify week performing areas (in the SC network) which need future improvement. In this context, most of the performance metrics being subjective in nature, a decision making group has been recommended to collect subjective evaluation information using linguistic scale. Linguistic information has been correlated with fuzzy logic to provide a strong mathematic base to support the aforesaid evaluation to facilitate various decision makings.

## 3.3 Basic Preliminaries of Fuzzy Mathematics

According to Rommelfanger, in real decision situations, we are often confronted with the problem that the very demanding conditions of classical decision models are often not fulfilled or the costs for getting this information seem too high. Subsequently, the decision maker usually abstains from constructing a decision model; he/she fears that this model may not exhibit a real image of his/her real problem. The fuzzy set theory offers the possibility to construct decision models with vague data. Motivated by this, present work aims at developing supply chain performance evaluation modules in fuzzy environment.

Real world decision making problems are too complex due to subjectivity and multi-possibility of evaluation data. Hence, decision making relies on subjective human judgment. The information collected from a group of experts (Decision Makers) expressed in linguistic terms are often vague in nature. The ambiguity and vagueness which is inherently present with subjective evaluation information cannot be tackled by traditional tools and techniques. Here, the application potential of fuzzy/grey numbers set theory deserves mention. The decision making module which explores subjective expert judgment is referred here as decision making with vague data set.

### 3.3.1 Theory of Generalized Trapezoidal Fuzzy Numbers (GTFNs) Set

Buckley (1984) investigated the problem of selecting, from a set of issues; those which could best satisfy a collection of criteria. A group of judges had fuzzy sets defined over the issues, for each criterion, whose values lied in a finite linearly ordered set £. These judges also had fuzzy sets defined over the set of criteria. The author discussed methods of aggregating all the fuzzy sets into one fuzzy set μ defined on the issues, so that $\mu(A) \in$ £ could give the final ranking for issue A.

In this paper, the author considered the problem of doing a study to select, from a set of issues $A_1$ . . . . . $A_m$, those which could best satisfy a collection of criteria $C_1$ . . . . . $C_K$. To carry out this project the author requested information from a group of judges $J_1$ . . . . . $J_n$, as to how well each issue satisfied each criterion and also how important each criterion was to the overall objective. It was assumed that each judge had a fuzzy set defined over the issues, for each criterion, with values in some linearly ordered set £. Also each judge had a fuzzy set defined over the criteria with values in £. The problem was how to aggregate these fuzzy sets into one fuzzy set μ on the issues with values in £ so that $\mu(A_i)$ was the final ranking for issue $A_i$.

In order to compute $\mu(A_i)$ the author discussed the following three problems:

(1) when to pool the judges,
(2) how to pool the judges, and
(3) how to finally compute the values of $\mu(A_i)$.

The study considered two ways to pool the experts: at the beginning or at the end. The major property imposed on the pooling functions was majority rule. It was showed that if n and k are odd, then the pooling functions must be the median operator. If n or k is even, then it was argued that it was very reasonable to still use the median operator (Buckley, 1984).
However, the decision making scenario as proposed by Buckley (1984) do not consider ranking of fuzzy numbers. However, the exploration of the theory of ranking of fuzzy numbers is seemed utmost important in the current scope of work since it aims to rank various SC performance sub-criterions based on their FPII values. FPII is represented by a fuzzy number; and hence, a unique ranking score is indeed required towards performance ranking of sub-criterions (corresponding FPIIs). In this context, the ranking theory as proposed by (Chen, 1985) deserves mention. It utilizes ''Maximizing Set and Minimizing Set'' approach towards computing left as well as right utility (corresponding to a fuzzy number), and, finally combining the two to compute am overall utility value. Based on the overall utility value, fuzzy numbers can be ranked accordingly. Thus, this work explores the theory of fuzzy numbers ranking by ''Maximizing Set and Minimizing Set'' approach towards identifying poor-performing SC areas.
In the concept of fuzzy logic, fuzzy numbers are generally represented by the type of their membership function. Triangular, trapezoidal, *Gaussian* membership functions are some of the examples. By the definition given by (Chen, 1985), a generalized trapezoidal fuzzy number can be defined as a vector shown below (Fig. 3.1).
$\tilde{A} = (a_1, a_2, a_3, a_4; w_{\tilde{A}})$, and the membership function $a(x): R \to [0,1]$ is defined as follows:

$$a(x) = \begin{cases} \dfrac{x-a_1}{a_2-a_1} \times w_{\tilde{A}}, & x \in (a_1, a_2) \\ w_{\tilde{A}}, & x \in (a_2, a_3) \\ \dfrac{x-a_4}{a_3-a_4} \times w_{\tilde{A}}, & x \in (a_3, a_4) \\ 0, & x \in (-\infty, a_1) \cup (a_4, \infty) \end{cases} \tag{3.1}$$

Here, $a_1 \le a_2 \le a_3 \le a_4$ and $w_{\tilde{A}} \in [0,1]$

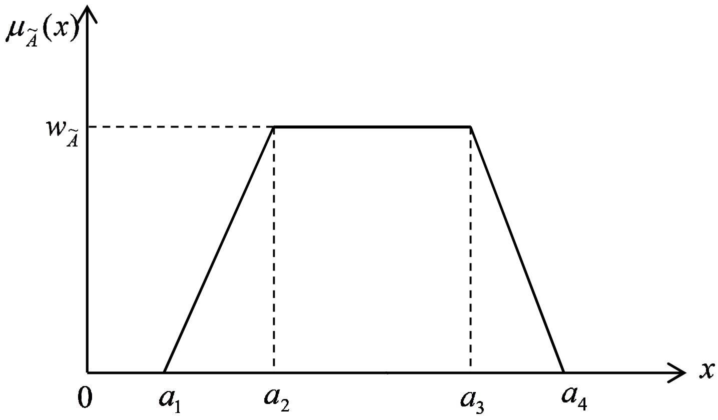



Fig. 3.1: Trapezoidal fuzzy number $\tilde{A}$

The elements of the generalized trapezoidal fuzzy numbers $x \in R$ are real numbers, and its membership function $a(x)$ is the regularly and continuous convex function, it shows that the membership degree to the fuzzy sets. If $-1 \le a_1 \le a_2 \le a_3 \le a_4 \le 1$, then $\tilde{A}$ is called the normalized trapezoidal fuzzy number. Especially, if $w_{\tilde{A}} = 1$, then $\tilde{A}$ is called trapezoidal fuzzy number $(a_1, a_2, a_3, a_4)$; if $a_1 < a_2 = a_3 < a_4$, then $\tilde{A}$ is reduced to a triangular fuzzy number. If $a_1 = a_2 = a_3 = a_4$, then $\tilde{A}$ is reduced to a real number.

Suppose that $\tilde{a} = (a_1, a_2, a_3, a_4; w_{\tilde{a}})$ and $\tilde{b} = (b_1, b_2, b_3, b_4; w_{\tilde{b}})$ are two generalized trapezoidal fuzzy numbers, then the operational rules of the generalized trapezoidal fuzzy numbers $\tilde{a}$ and $\tilde{b}$ are shown as follows (Chen and Chen, 2009):

$$\tilde{a} \oplus \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) \oplus (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$
$$(a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4; \min(w_{\tilde{a}}, w_{\tilde{b}})) \quad (3.2)$$

$$\tilde{a} - \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) - (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$
$$(a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1; \min(w_{\tilde{a}}, w_{\tilde{b}})) \quad (3.3)$$

$$\tilde{a} \otimes \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) \otimes (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$
$$(a, b, c, d; \min(w_{\tilde{a}}, w_{\tilde{b}})) \quad (3.4)$$

Here,

$$a = \min(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4)$$
$$b = \min(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3)$$
$$c = \max(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3)$$
$$d = \max(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4)$$

If $a_1, a_2, a_3, a_4, b_1, b_2, b_3, b_4$ are real numbers, then

$$\tilde{a} \otimes \tilde{b} = (a_1 \times b_1, a_2 \times b_2, a_3 \times b_3, a_4 \times b_4; \min(w_{\tilde{a}}, w_{\tilde{b}}))$$

$$\tilde{a} / \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) \big/ (b_1, b_2, b_3, b_4; w_{\tilde{b}})$$
$$= (a_1 / b_4, a_2 / b_3, a_3 / b_2, a_4 / b_1; \min(w_{\tilde{a}}, w_{\tilde{b}})) \quad (3.5)$$

Chen and Chen (2003) proposed the concept of COG point of generalized trapezoidal fuzzy numbers, and suppose that the COG point of the generalized trapezoidal fuzzy number $\tilde{a} = (a_1, a_2, a_3, a_4; w_{\tilde{a}})$ is $(x_{\tilde{a}}, y_{\tilde{a}})$, then:

$$y_{\tilde{a}} = \begin{cases} \dfrac{w_{\tilde{a}} \times \left( \dfrac{a_3 - a_2}{a_4 - a_1} + 2 \right)}{6}, & if\ a_1 \neq a_4 \\ \dfrac{w_{\tilde{a}}}{2}, & if\ a_1 = a_4 \end{cases}$$
$$x_{\tilde{a}} = \frac{y_{\tilde{a}} \times (a_2 + a_3) + (a_1 + a_4) \times (w_{\tilde{a}} - y_{\tilde{a}})}{2 \times w_{\tilde{a}}} \quad (3.6)$$

### 3.3.2 Ranking of Generalized Fuzzy Numbers using Maximizing Set and Minimizing Set

The ranking methodology adapted here has been described as follows (Chou et al., 2011). Let us consider $n$ normal fuzzy numbers $A_i, (i = 1,2,...,n)$, each with a trapezoidal membership function $f_{A_i}(x)$. The revised method performs pair-wise comparisons on the $n$ fuzzy numbers.

For each pair of fuzzy numbers, say $A_1$ and $A_2$, the pair-wise comparison are preceded as follows.

The maximizing set $M$ and minimizing set $G$ with membership function $f_M$ is given as,

$$f_M(x) = \begin{cases} \left[ (x - x_{\min}) \big/ (x_{\max} - x_{\min}) \right]^k, & x_{\min} \le x \le x_{\max} \\ 0, & Otherwise. \end{cases} \quad (3.7)$$

The minimizing set $G$ is a fuzzy subset with membership function $f_G$ is given as,

$$f_G(x) = \begin{cases} \left[ (x_{\max} - x) \big/ (x_{\max} - x_{\min}) \right]^k, & x_{\min} \le x \le x_{\max} \\ 0, & Otherwise. \end{cases} \quad (3.8)$$

Here $x_{\min} = Inf\ S, x_{\max} = Sup\ S, S = U_{i=1}^{n} S_i, S_i = \{x / f_{A_i}(x) \succ 0\}$, and $k$ is set to be 1. The revised ranking method defines the right utility values of each alternative $A_i$ as:

$$u_{M_{i1}}(i) = \sup_x \left( f_M(x) \wedge f_{A_i^R}(x) \right), \ i = 1,2; \quad (3.9)$$

$$u_{G_{i2}}(i) = \sup_x \left( f_G(x) \wedge f_{A_i^R}(x) \right), \ i = 1,2. \quad (3.10)$$

The let utility values of each alternative $A_i$ as:

$$u_{G_{i1}}(i) = \sup_x \left( f_G(x) \wedge f_{A_i^L}(x) \right), \ i = 1,2; \quad (3.11)$$

$$u_{M_{i2}}(i) = \sup_x \left( f_M(x) \wedge f_{A_i^L}(x) \right), \ i = 1,2. \quad (3.12)$$

The revised ranking method defines the total utility value of each fuzzy number $A_i$ with index of optimism $\alpha$ as:

$$U_T^{\alpha}(i) = \frac{1}{2} \left[ \alpha \{ u_{M_{i1}}(i) + 1 - u_{G_{i2}}(i) \} + (1 - \alpha) \{ u_{M_{i2}}(i) + 1 - u_{G_{i1}}(i) \} \right], \ i = 1,2. \quad (3.13)$$

The index of optimism $(\alpha)$ represents the degree of optimism of a decision-maker (Kim and Park, 1990; Liou and Wang, 1992; Wang and Luo, 2009). A larger $\alpha$ indicates a higher degree of optimism. More specifically, when $\alpha = 0$, the total utility value $u_T^0(A_i)$ representing a pessimistic decision-maker's viewpoint is equal to the total left utility value of $A_i$. Conversely, for an optimistic decision maker, i.e. $\alpha = 1$, the total utility value $u_T^1(A_i)$ is equal to the total right utility value of $A_i$. For a moderate (neutral) decision-maker, with $\alpha = 0.5$, the total utility value of each fuzzy number $A_i$ become

$$U_T^{1/2}(i) = \frac{1}{2}\left[\frac{1}{2}\left\{u_{M_{i1}}(i) + 1 - u_{G_{i2}}(i)\right\} + \frac{1}{2}\left\{u_{M_{i2}}(i) + 1 - u_{G_{i1}}(i)\right\}\right],\ i = 1,2. \quad (3.14)$$

The greater the $u_T^{\alpha}(A_i)$, the bigger the fuzzy number $A_i$ and the higher it's ranking order.

As described by (Chou et al., 2011), if $A_i$ is a normal trapezoidal fuzzy number, i.e. $A_i = (a_i, b_i, c_i, d_i; 1)$, the total utility value of each fuzzy number $A_i$ can be written as:

$$u_T^{\alpha}(i) = \frac{1}{2}\left(\begin{array}{l}\alpha\left[\dfrac{d_i - x_{\min}}{d_i - c_i + x_{\max} - x_{\min}} + \dfrac{c_i - x_{\min}}{c_i - d_i + x_{\max} - x_{\min}}\right] + \\ (1-\alpha)\left[\dfrac{a_i - x_{\min}}{a_i - b_i + x_{\max} - x_{\min}} + \dfrac{b_i - x_{\min}}{b_i - a_i + x_{\max} - x_{\min}}\right]\end{array}\right) \quad (3.15)$$

### 3.3.3 Concept of Fuzzy Degree of Similarity between two GTFNs

For any two generalized trapezoidal fuzzy numbers,

$\tilde{\tilde{A}} = (a_1, a_2, a_3, a_4)$ and $\tilde{\tilde{B}} = (b_1, b_2, b_3, b_4)$

The degree of similarity $S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right)$ between two fuzzy numbers $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ can be computed as follows:

1. The similarity measure (Chen, 1996)

$$S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = 1 - \frac{\sum_{i=1}^{4}\left|a_i - b_i\right|}{4} \quad (3.16)$$

2. In (Hsieh and Chen, 1999)

$$S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = \frac{1}{1 + d\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right)} \quad (3.17)$$

Here $d\left(\tilde{\tilde{A}},\tilde{\tilde{B}}\right)=\left|P\left(\tilde{\tilde{A}}\right)-P\left(\tilde{\tilde{B}}\right)\right|$

$$P\left(\tilde{\tilde{A}}\right)=\frac{a_1+2a_2+2a_3+a_4}{6},\ P\left(\tilde{\tilde{B}}\right)=\frac{b_1+2b_2+2b_3+b_4}{6} \qquad (3.18)$$

3. Simple centre of gravity method (Chen and Chen, 2003)

The SCGM is based on the concept of medium curve (Subasic and Hirota, 1998). The SCGM method integrates the concepts of geometric distance and the COG distance of GFN's. If the GFN's are $\tilde{\tilde{A}}=\left(a_1,a_2,a_3,a_4;w_{\tilde{\tilde{A}}}\right)$ and $\tilde{\tilde{B}}=\left(b_1,b_2,b_3,b_4;w_{\tilde{\tilde{B}}}\right)$ and $0\le a_1\le a_2\le a_3\le a_4\le 1$ and $0\le b_1\le b_2\le b_3\le b_4\le 1$.

$COG\left(\tilde{\tilde{A}}\right)=\left(x^*_{\tilde{\tilde{A}}},y^*_{\tilde{\tilde{A}}}\right), COG\left(\tilde{\tilde{B}}\right)=\left(x^*_{\tilde{\tilde{B}}},y^*_{\tilde{\tilde{B}}}\right)$ then

$$S\left(\tilde{\tilde{A}},\tilde{\tilde{B}}\right)=1-\frac{\sum_{i=1}^{4}\left|a_i-b_i\right|}{4}\left(1-\left|x^*_{\tilde{\tilde{A}}}-x^*_{\tilde{\tilde{B}}}\right|\right)^{B\left(S_{\tilde{\tilde{A}}},S_{\tilde{\tilde{B}}}\right)}\frac{\min\left(y^*_{\tilde{\tilde{A}}},y^*_{\tilde{\tilde{B}}}\right)}{\max\left(y^*_{\tilde{\tilde{A}}},y^*_{\tilde{\tilde{B}}}\right)} \qquad (3.19)$$

Here

$$y^*_A=\begin{cases}\dfrac{w_{\tilde{\tilde{A}}}\left(\dfrac{a_3-a_2}{a_4-a_1}+2\right)}{6}, & if\ a_1\ne a_4,\\ \dfrac{w_{\tilde{\tilde{A}}}}{2}, & if\ a_1=a_4.\end{cases} \qquad (3.20)$$

$$x^*_{\tilde{\tilde{A}}}=\frac{y^*_{\tilde{\tilde{A}}}\left(a_3+a_2\right)+\left(a_4+a_1\right)\left(w_{\tilde{\tilde{A}}}-y^*_{\tilde{\tilde{A}}}\right)}{2w_{\tilde{\tilde{A}}}} \qquad (3.21)$$

$$B\left(S_{\tilde{\tilde{A}}},S_{\tilde{\tilde{B}}}\right)=\begin{cases}1 & if\ S_A+S_B>0\\ 0 & if\ S_A+S_B=0\end{cases} \qquad (3.22)$$

$$S_A=a_4-a_1;\ S_B=b_4-b_1 \qquad (3.23)$$

4. The radius of gyration based similarity measure (Yong et al., 2004)

$$S\left(\tilde{\tilde{A}},\tilde{\tilde{B}}\right)=1-\frac{\sum_{i=1}^{4}\left|a_i-b_i\right|}{4}\left(1-\left|r_x^{\tilde{\tilde{A}}}-r_x^{\tilde{\tilde{B}}}\right|\right)^{B\left(S_{\tilde{\tilde{A}}},S_{\tilde{\tilde{B}}}\right)}\frac{\min\left(r_y^{\tilde{\tilde{A}}},r_y^{\tilde{\tilde{B}}}\right)}{\max\left(r_y^{\tilde{\tilde{A}}},r_y^{\tilde{\tilde{B}}}\right)} \tag{3.24}$$

Here

$$r_x^{\tilde{\tilde{A}}}=\sqrt{\frac{(I_x)_1+(I_x)_2+(I_x)_3}{\{(a_3-a_2)+(a_4-a_1)\}\frac{w_{\tilde{\tilde{A}}}}{2}}} \tag{3.25}$$

$$r_y^{\tilde{\tilde{A}}}=\sqrt{\frac{(I_y)_1+(I_y)_2+(I_y)_3}{\{(a_3-a_2)+(a_4-a_1)\}\frac{w_{\tilde{\tilde{A}}}}{2}}} \tag{3.26}$$

$$(I_x)_1=\frac{(a_2-a_1)w_{\tilde{\tilde{A}}}^3}{12} \tag{3.27}$$

$$(I_x)_2=\frac{(a_3-a_2)w_{\tilde{\tilde{A}}}^3}{3} \tag{3.28}$$

$$(I_x)_3=\frac{(a_4-a_3)w_{\tilde{\tilde{A}}}^3}{12} \tag{3.29}$$

$$(I_y)_1=\frac{(a_2-a_1)^3 w_{\tilde{\tilde{A}}}}{4}+\frac{(a_2-a_1)a_1^2 w_{\tilde{\tilde{A}}}}{2}+\frac{2(a_2-a_1)^2 a_1 w_{\tilde{\tilde{A}}}}{3} \tag{3.30}$$

$$(I_y)_2=\frac{(a_3-a_2)^3 w_{\tilde{\tilde{A}}}}{3}+\frac{(a_3-a_2)a_2^2 w_{\tilde{\tilde{A}}}}{1}+\frac{2(a_3-a_2)^2 a_2 w_{\tilde{\tilde{A}}}}{1} \tag{3.31}$$

$$(I_y)_3=\frac{(a_4-a_3)^3 w_{\tilde{\tilde{A}}}}{12}+\frac{(a_4-a_3)a_3^2 w_{\tilde{\tilde{A}}}}{2}+\frac{2(a_4-a_3)^2 a_1 w_{\tilde{\tilde{A}}}}{3} \tag{3.32}$$

5. Similarity measure based on geometric mean averaging operator (Chen, 2006)

$$S\left(\tilde{\tilde{A}},\tilde{\tilde{B}}\right)=\left[\sqrt[4]{\prod_{i=1}^{4}\left(2-\left|a_i-b_i\right|\right)}-1\right]\times\frac{\min\left(y_{\tilde{\tilde{A}}}^*,y_{\tilde{\tilde{B}}}^*\right)}{\max\left(y_{\tilde{\tilde{A}}}^*,y_{\tilde{\tilde{B}}}^*\right)} \tag{3.33}$$

Here $y_{\tilde{\tilde{A}}}^*,y_{\tilde{\tilde{B}}}^*$ are given by Eq. (3.20).

6. Fuzzy similarity measure proposed by (Sridevi and Nadarajan, 2009)

(Sridevi and Nadarajan, 2009) presented a new similarity measure based on fuzzy difference of distance of points of fuzzy numbers rather than geometric distances used by the existing methods.

The membership function to measure the difference in distance of points of two GFN's is defined as

$$\mu_d(x) = \begin{cases} 1 - \dfrac{x}{d}, 0 \le x \le d \\ 0, Otherwise. \end{cases} \tag{3.34}$$

Here $0 < d \le 1$ and $x = |a_i - b_i|$. The degree of similarity of two GFN's $\approx A$ and $\approx B$ is defined as

$$S\left(\overset{\approx}{A}, \overset{\approx}{B}\right) = \frac{1}{4}\sum_{i=1}^{4} \mu_d(x)\left(1 - \left|x^*_{\overset{\approx}{A}} - x^*_{\overset{\approx}{B}}\right|\right)^{B\left(S_{\overset{\approx}{A}}, S_{\overset{\approx}{B}}\right)} \frac{\min\left(y^*_{\overset{\approx}{A}}, y^*_{\overset{\approx}{B}}\right)}{\max\left(y^*_{\overset{\approx}{A}}, y^*_{\overset{\approx}{B}}\right)} \tag{3.35}$$

$B\left(S_{\overset{\approx}{A}}, S_{\overset{\approx}{B}}\right)$ is 0 or 1 according as COG point is considered or not and $x^*_{\overset{\approx}{A}}, x^*_{\overset{\approx}{B}}, y^*_{\overset{\approx}{A}}, y^*_{\overset{\approx}{B}}$ are given in Eqs. (3.20-3.21).

## 3.3.4 Theory of Generalized Interval-Valued Fuzzy Numbers (GIVFNs) Set

The theory of Generalized Interval-Valued Fuzzy Numbers (GIVFNs) has been provided below. In fuzzy set theory, it is often difficult for an expert to exactly quantify his/ her opinion as a number in interval $[0,1]$. Therefore, it is more suitable to represent this degree of certainty by an interval. (Sambuc, 1975) and (Grattan-Guinness, 1975) noted that the presentation of a linguistic expression in the form of fuzzy sets is not enough. Interval-valued fuzzy sets (IVFS) were suggested for the first time by (Gorzlczany, 1987). Also (Corneils et al., 2006) and (Karnik and Mendel, 2001) noted that the main reason for proposing this concept is the fact that, in the linguistic modeling of a phenomenon, the presentation of the linguistic expression in the form of ordinary fuzzy sets is not clear enough. (Wang and Li, 1998) defined Interval-Valued Fuzzy Numbers (IVFNs) and gave their extended operations. Based on definition of IVFS in (Gorzlczany, 1987), an IVFS as defined on $(-\infty, +\infty)$ is given by:

$$A = \{(x, [\mu_A^L(x), \mu_A^U(x)])\} \tag{3.36}$$
$$\mu_A^L, \mu_A^U : X \to [0,1] \qquad \forall x \in X, \quad \mu_A^L \leq \mu_A^U$$
$$\overline{\mu}_A(x) = [\mu_A^L(x), \mu_A^U(x)]$$
$$A = \{(x, \overline{\mu}_A(x))\}, x \in (-\infty, +\infty)$$

Here, $\mu_A^L(x)$ is the lower limit of the degree of membership and $\mu_A^U(x)$ is the upper limit of the degree of membership.

Let, two IVFNs $N_x = [N_x^-; N_x^+]$ and $M_y = [M_y^-; M_y^+]$, according to (Gorzlczany, 1987), we have:

**Definition 1:** If, $. \in (+, -, \times, \div)$, then $N.M(x.y) = [N_x^-.M_y^-; N_x^+.M_y^+]$, for a positive nonfuzzy number $(\upsilon)$, and $\upsilon.M(x, y) = [\upsilon.M_y^-; \upsilon.M_y^+]$.

**Definition 2:** The intersection of two IVFS (Gorzlczany, 1987) is defined as the minimum of their respective lower and upper bounds of their membership intervals. Given two intervals of $[0,1]$ and $N_x = [N_x^-; N_x^+] \subset [0,1]$, $M_y = [M_y^-; M_y^+] \subset [0,1]$, the minimum of both intervals is an interval $K = MIN(N_x, M_y) = [MIN(N_x^-, M_y^-), MIN(N_x^+, M_y^+)]$.

**Definition 3:** The union of two IVFS (Gorzlczany, 1987) is defined as the maximum of their respective lower and upper bounds of their membership intervals. Given two intervals of $[0,1]$ and $N_x = [N_x^-; N_x^+] \subset [0,1]$, $M_y = [M_y^-; M_y^+] \subset [0,1]$, the maximum of both intervals is an interval $K = MAX(N_x, M_y) = [MAX(N_x^-, M_y^-), MAX(N_x^+, M_y^+)]$.

In order to ensure reliability and also to improve effectiveness of the decision-making process, instead of using generalized trapezoidal fuzzy numbers, IV-trapezoidal fuzzy numbers are to be used (Wei and Chen, 2009).

Wang and Li (2001) represented the interval-valued trapezoidal fuzzy numbers as follows (Fig. 3.2):

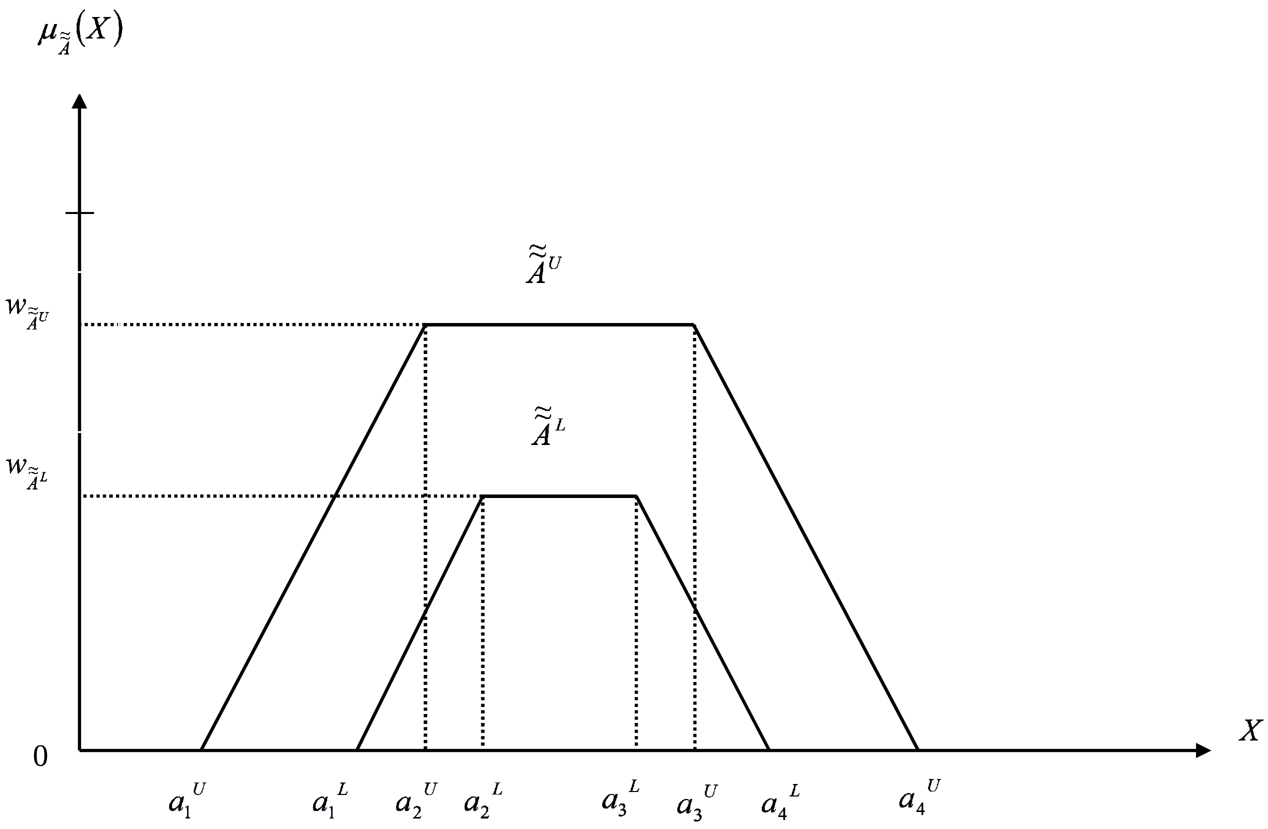



Fig. 3.2: Interval-valued trapezoidal fuzzy numbers

$$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right]$$

$0 \le a_1^L \le a_2^L \le a_3^L \le a_4^L \le 1,$

Here, $0 \le a_1^U \le a_2^U \le a_3^U \le a_4^U \le 1,$ and $\tilde{\tilde{A}}^L \subset \tilde{\tilde{A}}^U$.

$0 \le w_{\tilde{\tilde{A}}^L} \le w_{\tilde{\tilde{A}}^U}$

From Fig. 3.2, it can be concluded that interval-valued trapezoidal fuzzy number $\tilde{\tilde{A}}$ consists of the lower values of interval-valued trapezoidal fuzzy number $\tilde{\tilde{A}}^L$ and the upper values of interval-valued trapezoidal fuzzy number $\tilde{\tilde{A}}^U$.

The operation rules of IV Trapezoidal Fuzzy Numbers are as follows:

Suppose that,

$\tilde{\tilde{A}} = \left[ \tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U \right] = \left[ \left( a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L} \right), \left( a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U} \right) \right]$ and

$\tilde{\tilde{B}} = \left[ \tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U \right] = \left[ \left( b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L} \right), \left( b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U} \right) \right]$ are the two interval-valued trapezoidal fuzzy numbers, where,

$$0 \le a_1^L \le a_2^L \le a_3^L \le a_4^L \le 1,$$
$$0 \le a_1^U \le a_2^U \le a_3^U \le a_4^U \le 1,$$
$$0 \le w_{\tilde{\tilde{A}}^L} \le w_{\tilde{\tilde{A}}^U} \le 1, \quad \tilde{\tilde{A}}^L \subset \tilde{\tilde{A}}^U$$

$$0 \le b_1^L \le b_2^L \le b_3^L \le b_4^L \le 1,$$
$$0 \le b_1^U \le b_2^U \le b_3^U \le b_4^U \le 1,$$
$$0 \le w_{\tilde{\tilde{B}}^L} \le w_{\tilde{\tilde{B}}^U} \le 1, \quad \tilde{\tilde{B}}^L \subset \tilde{\tilde{B}}^U$$

The sum of two interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}} \oplus \tilde{\tilde{B}}$:

$$\tilde{\tilde{A}} \oplus \tilde{\tilde{B}} = \left[ \left( a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L} \right), \left( a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U} \right) \right] \oplus \left[ \left( b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L} \right), \left( b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U} \right) \right]$$
$$= \left[ \left( a_1^L + b_1^L, a_2^L + b_2^L, a_3^L + b_3^L, a_4^L + b_4^L; \min\left( w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L} \right) \right), \left( a_1^U + b_1^U, a_2^U + b_2^U, a_3^U + b_3^U, a_4^U + b_4^U; \min\left( w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U} \right) \right) \right] \tag{3.37}$$

The difference of two interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}} - \tilde{\tilde{B}}$:

$$\tilde{\tilde{A}} - \tilde{\tilde{B}} = \left[ \left( a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L} \right), \left( a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U} \right) \right] - \left[ \left( b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L} \right), \left( b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U} \right) \right]$$
$$= \left[ \left( a_1^L - b_4^L, a_2^L - b_3^L, a_3^L - b_2^L, a_4^L - b_1^L; \min\left( w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L} \right) \right), \left( a_1^U - b_4^U, a_2^U - b_3^U, a_3^U - b_2^U, a_4^U - b_1^U; \min\left( w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U} \right) \right) \right] \tag{3.38}$$

The product of two interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}} \otimes \tilde{\tilde{B}}$:

$$\tilde{\tilde{A}} \otimes \tilde{\tilde{B}} = \left[ \left( a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L} \right), \left( a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U} \right) \right] \otimes \left[ \left( b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L} \right), \left( b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U} \right) \right]$$
$$= \left[ \left( a_1^L \times b_1^L, a_2^L \times b_2^L, a_3^L \times b_3^L, a_4^L \times b_4^L; \min\left( w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L} \right) \right), \left( a_1^U \times b_1^U, a_2^U \times b_2^U, a_3^U \times b_3^U, a_4^U \times b_4^U; \min\left( w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U} \right) \right) \right] \tag{3.39}$$

The quotient of two interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}} / \tilde{\tilde{B}}$:

$$\tilde{\tilde{A}} / \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right] / \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$$

$$= \left[\left(a_1^L / b_4^L, a_2^L / b_3^L, a_3^L / b_2^L, a_4^L / b_1^L; \min\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right)\right), \left(a_1^U / b_4^U, a_2^U / b_3^U, a_3^U / b_2^U, a_4^U / b_1^U; \min\left(w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U}\right)\right)\right]$$

(3.40)

The product between an interval-valued trapezoidal fuzzy number and a constant $\lambda\tilde{\tilde{A}}$:

$$\lambda\tilde{\tilde{A}} = \lambda \times \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right]$$

$$= \left[\left(\lambda a_1^L, \lambda a_2^L, \lambda a_3^L, \lambda a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(\lambda a_1^U, \lambda a_2^U, \lambda a_3^U, \lambda a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right], \quad \lambda > 0. \qquad (3.41)$$

The distance of IV Trapezoidal Fuzzy Numbers is measured as follows:

Suppose that,

$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right]$ and

$\tilde{\tilde{B}} = \left[\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U\right] = \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$ are the two generalized interval-valued trapezoidal fuzzy numbers, then the distance of two interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ is calculated as follows:

a. Utilize the Eq. (3.6) to calculate the coordinate of COG points $\left(x_{\tilde{\tilde{A}}^L}, y_{\tilde{\tilde{A}}^L}\right), \left(x_{\tilde{\tilde{A}}^U}, y_{\tilde{\tilde{A}}^U}\right), \left(x_{\tilde{\tilde{B}}^L}, y_{\tilde{\tilde{B}}^L}\right), \left(x_{\tilde{\tilde{B}}^U}, y_{\tilde{\tilde{B}}^U}\right)$ which belong to the generalized interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U, \tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U$.

b. The distance of two interval-valued trapezoidal fuzzy number is:

$$d\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = \frac{1}{2}\sqrt{\left\{\left(y_{\tilde{\tilde{A}}^L} - y_{\tilde{\tilde{B}}^L}\right)^2 + \left(x_{\tilde{\tilde{A}}^L} - x_{\tilde{\tilde{B}}^L}\right)^2 + \left(y_{\tilde{\tilde{A}}^U} - y_{\tilde{\tilde{B}}^U}\right)^2 + \left(x_{\tilde{\tilde{A}}^U} - x_{\tilde{\tilde{B}}^U}\right)^2\right\}} \qquad (3.42)$$

Here, $d\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right)$ satisfies the following properties:

(i) If $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ are normalized interval-valued trapezoidal fuzzy numbers, then $0 \le d\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) \le 1$.

(ii) $\tilde{\tilde{A}} = \tilde{\tilde{B}} \Rightarrow d\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = 0$

(iii) $d\left(\approx{A}, \approx{B}\right) = d\left(\approx{B}, \approx{A}\right)$

(iv) $d\left(\approx{A}, \approx{C}\right) + d\left(\approx{C}, \approx{B}\right) \geq d\left(\approx{A}, \approx{B}\right)$

### 3.3.5 Concept of Fuzzy Degree of Similarity between two GIVFNs

Combining the concepts of geometric distance, the perimeter, the height and the COG points, the degree of similarity between interval-valued trapezoidal fuzzy numbers can be calculated (Wei and Chen, 2009). Assuming that there are two interval-valued trapezoidal fuzzy numbers:

$$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; \hat{w}_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; \hat{w}_{\tilde{\tilde{A}}}^U\right)\right]$$ and

$$\tilde{\tilde{B}} = \left[\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U\right] = \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; \hat{w}_{\tilde{\tilde{B}}}^L\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; \hat{w}_{\tilde{\tilde{B}}}^U\right)\right]$$

Here, $0 \leq a_1^L \leq a_2^L \leq a_3^L \leq a_4^L \leq 1, \quad 0 \leq a_1^U \leq a_2^U \leq a_3^U \leq a_4^U \leq 1,$

$0 \leq \hat{w}_{\tilde{\tilde{A}}}^L \leq w_{\tilde{\tilde{A}}}^U \leq 1, \ \tilde{\tilde{A}}^L \subset \tilde{\tilde{A}}^U.$

$0 \leq b_1^L \leq b_2^L \leq b_3^L \leq b_4^L \leq 1, \quad 0 \leq b_1^U \leq b_2^U \leq b_3^U \leq b_4^U \leq 1,$

$0 \leq \hat{w}_{\tilde{\tilde{B}}}^L \leq w_{\tilde{\tilde{B}}}^U \leq 1, \ \tilde{\tilde{B}}^L \subset \tilde{\tilde{B}}^U.$

The procedural steps for calculating the degree of similarity between interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ are summarized below (Wei and Chen, 2009).

Step 1: Calculate the areas $A\left(\tilde{\tilde{A}}^L\right)$ and $A\left(\tilde{\tilde{A}}^U\right)$ of the lower trapezoidal fuzzy number $\tilde{\tilde{A}}^L$ and the upper trapezoidal fuzzy number $\tilde{\tilde{A}}^U$, respectively, shown as follows:

$$A\left(\tilde{\tilde{A}}^L\right) = \frac{\left(a_4^L + a_3^L - a_2^L - a_1^L\right) \times \hat{w}_{\tilde{\tilde{A}}^L}}{2}, \quad (3.43)$$

$$A\left(\tilde{\tilde{A}}^U\right) = \frac{\left(a_4^U + a_3^U - a_2^U - a_1^U\right) \times \hat{w}_{\tilde{\tilde{A}}^U}}{2}. \quad (3.44)$$

In the same way, calculate the areas $A\left(\tilde{\tilde{B}}^L\right)$ and $A\left(\tilde{\tilde{B}}^U\right)$ of the lower trapezoidal fuzzy number $\tilde{\tilde{B}}^L$ and the upper trapezoidal fuzzy number $\tilde{\tilde{B}}^U$, respectively, shown as follows:

$$A\left(\tilde{\tilde{B}}^L\right) = \frac{\left(b_4^L + b_3^L - b_2^L - b_1^L\right) \times \hat{w}_{\tilde{\tilde{B}}^L}}{2}, \quad (3.45)$$

$$A\left(\tilde{\tilde{B}}^U\right) = \frac{\left(b_4^U + b_3^U - b_2^U - b_1^U\right) \times \hat{w}_{\tilde{\tilde{B}}^U}}{2}. \quad (3.46)$$

<u>Step 2:</u> Calculate the COG points $\left(x^*_{\tilde{\tilde{A}}^L}, y^*_{\tilde{\tilde{A}}^L}\right), \left(x^*_{\tilde{\tilde{A}}^U}, y^*_{\tilde{\tilde{A}}^U}\right), \left(x^*_{\tilde{\tilde{B}}^L}, y^*_{\tilde{\tilde{B}}^L}\right), \left(x^*_{\tilde{\tilde{B}}^U}, y^*_{\tilde{\tilde{B}}^U}\right)$ of $\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U$ and $\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U$, respectively, by Eqs. (3.47-3.54).

$$x^*_{\tilde{\tilde{A}}^L} = \frac{y^*_{\tilde{\tilde{A}}^L}\left(a_3^L + a_2^L\right) + \left(a_4^L + a_1^L\right)\left(\hat{w}_{\tilde{\tilde{A}}^L} - y^*_{\tilde{\tilde{A}}^L}\right)}{2\hat{w}_{\tilde{\tilde{A}}^L}} \quad (3.47)$$

$$y^*_{\tilde{\tilde{A}}^L} = \begin{cases} \dfrac{\hat{w}_{\tilde{\tilde{A}}^L}\left(\dfrac{a_3^L - a_2^L}{a_4^L - a_1^L} + 2\right)}{6}, & \text{if } a_1^L \neq a_4^L \text{ and } 0 < \hat{w}_{\tilde{\tilde{A}}^L} \leq 1, \\ \dfrac{\hat{w}_{\tilde{\tilde{A}}^L}}{2}, & \text{if } a_1^L = a_4^L \text{ and } 0 < \hat{w}_{\tilde{\tilde{A}}^L} \leq 1. \end{cases} \quad (3.48)$$

$$x^*_{\tilde{\tilde{A}}^U} = \frac{y^*_{\tilde{\tilde{A}}^U}\left(a_3^U + a_2^U\right) + \left(a_4^U + a_1^U\right)\left(\hat{w}_{\tilde{\tilde{A}}^U} - y^*_{\tilde{\tilde{A}}^U}\right)}{2\hat{w}_{\tilde{\tilde{A}}^U}} \quad (3.49)$$

$$y^*_{\tilde{\tilde{A}}^U} = \begin{cases} \dfrac{\hat{w}_{\tilde{\tilde{A}}^U}\left(\dfrac{a_3^U - a_2^U}{a_4^U - a_1^U} + 2\right)}{6}, & if \ \ a_1^U \neq a_4^U \ \ and \ 0 < \hat{w}_{\tilde{\tilde{A}}^U} \leq 1, \\ \dfrac{\hat{w}_{\tilde{\tilde{A}}^U}}{2}, & if \ \ a_1^U = a_4^U \ \ and \ 0 < \hat{w}_{\tilde{\tilde{A}}^U} \leq 1. \end{cases} \tag{3.50}$$

$$x^*_{\tilde{\tilde{B}}^L} = \frac{y^*_{\tilde{\tilde{B}}^L}\left(b_3^L + b_2^L\right) + \left(b_4^L + b_1^L\right)\left(\hat{w}_{\tilde{\tilde{B}}^L} - y^*_{\tilde{\tilde{B}}^L}\right)}{2\hat{w}_{\tilde{\tilde{B}}^L}} \tag{3.51}$$

$$y^*_{\tilde{\tilde{B}}^L} = \begin{cases} \dfrac{\hat{w}_{\tilde{\tilde{B}}^L}\left(\dfrac{b_3^L - b_2^L}{b_4^L - b_1^L} + 2\right)}{6}, & if \ \ b_1^L \neq b_4^L \ \ and \ 0 < \hat{w}_{\tilde{\tilde{B}}^L} \leq 1, \\ \dfrac{\hat{w}_{\tilde{\tilde{B}}^L}}{2}, & if \ \ b_1^L = b_4^L \ \ and \ 0 < \hat{w}_{\tilde{\tilde{B}}^L} \leq 1. \end{cases} \tag{3.52}$$

$$x^*_{\tilde{\tilde{B}}^U} = \frac{y^*_{\tilde{\tilde{B}}^U}\left(b_3^U + b_2^U\right) + \left(b_4^U + b_1^U\right)\left(\hat{w}_{\tilde{\tilde{B}}^U} - y^*_{\tilde{\tilde{B}}^U}\right)}{2\hat{w}_{\tilde{\tilde{B}}^U}} \tag{3.53}$$

$$y^*_{\tilde{\tilde{B}}^U} = \begin{cases} \dfrac{\hat{w}_{\tilde{\tilde{B}}^U}\left(\dfrac{b_3^U - b_2^U}{b_4^U - b_1^U} + 2\right)}{6}, & if \ \ b_1^U \neq b_4^U \ \ and \ 0 < \hat{w}_{\tilde{\tilde{B}}^U} \leq 1, \\ \dfrac{\hat{w}_{\tilde{\tilde{B}}^U}}{2}, & if \ \ b_1^U = b_4^U \ \ and \ 0 < \hat{w}_{\tilde{\tilde{B}}^U} \leq 1. \end{cases} \tag{3.54}$$

<u>Step 3:</u> Calculate the COG point $\left(x^*_{\tilde{\tilde{A}}}, y^*_{\tilde{\tilde{A}}}\right)$ of the interval-valued fuzzy number $\tilde{\tilde{A}}$, where

$$x^*_{\tilde{\tilde{A}}} = \begin{cases} \dfrac{A\left(\tilde{\tilde{A}}^U\right) \times x^*_{\tilde{\tilde{A}}^U} - A\left(\tilde{\tilde{A}}^L\right) \times x^*_{\tilde{\tilde{A}}^L}}{A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right)}, & if \ \ A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right) \neq 0, \\ 0, & otherwise. \end{cases} \tag{3.55}$$

$$y^*_{\tilde{\tilde{A}}} = \begin{cases} \dfrac{A\left(\tilde{\tilde{A}}^U\right)\times y^*_{\tilde{\tilde{A}}^U} - A\left(\tilde{\tilde{A}}^L\right)\times y^*_{\tilde{\tilde{A}}^L}}{A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right)}, & if\ A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right) \neq 0, \\ 0, & otherwise. \end{cases} \tag{3.56}$$

In the same way, calculate the COG point $\left(x^*_{\tilde{\tilde{B}}}, y^*_{\tilde{\tilde{B}}}\right)$ of the interval-valued fuzzy number $\tilde{\tilde{B}}$, where

$$x^*_{\tilde{\tilde{B}}} = \begin{cases} \dfrac{A\left(\tilde{\tilde{B}}^U\right)\times x^*_{\tilde{\tilde{B}}^U} - A\left(\tilde{\tilde{B}}^L\right)\times x^*_{\tilde{\tilde{B}}^L}}{A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right)}, & if\ A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right) \neq 0, \\ 0, & otherwise. \end{cases} \tag{3.57}$$

$$y^*_{\tilde{\tilde{B}}} = \begin{cases} \dfrac{A\left(\tilde{\tilde{B}}^U\right)\times y^*_{\tilde{\tilde{B}}^U} - A\left(\tilde{\tilde{B}}^L\right)\times y^*_{\tilde{\tilde{B}}^L}}{A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right)}, & if\ A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right) \neq 0, \\ 0, & otherwise. \end{cases} \tag{3.58}$$

<u>Step 4</u>: Calculate the degree of similarity $S\left(\tilde{\tilde{A}}^L, \tilde{\tilde{B}}^L\right)$ between the lower trapezoidal fuzzy numbers $\tilde{\tilde{A}}^L$ and $\tilde{\tilde{B}}^L$, shown as follows:

$$S\left(\tilde{\tilde{A}}^L, \tilde{\tilde{B}}^L\right) = \begin{cases} \left[1 - \dfrac{\sum_{i=1}^{4}\left|a_i^L - b_i^L\right|}{4}\right] \times \dfrac{\min\left(L\left(\tilde{\tilde{A}}^L\right), L\left(\tilde{\tilde{B}}^L\right)\right) + \min\left(\hat{w}_{\tilde{\tilde{A}}^L}, \hat{w}_{\tilde{\tilde{B}}^L}\right)}{\max\left(L\left(\tilde{\tilde{A}}^L\right), L\left(\tilde{\tilde{B}}^L\right)\right) + \max\left(\hat{w}_{\tilde{\tilde{A}}^L}, \hat{w}_{\tilde{\tilde{B}}^L}\right)}, & if\ \min\left(\hat{w}_{\tilde{\tilde{A}}^L}, \hat{w}_{\tilde{\tilde{B}}^L}\right) \neq 0, \\ 0, & otherwise. \end{cases} \tag{3.59}$$

Here,

$$L\left(\tilde{\tilde{A}}^L\right) = \sqrt{\left(a_1^L - a_2^L\right)^2 + \hat{w}^2_{\tilde{\tilde{A}}^L}} + \sqrt{\left(a_3^L - a_4^L\right)^2 + \hat{w}^2_{\tilde{\tilde{A}}^L}} + \left(a_3^L - a_2^L\right) + \left(a_4^L - a_1^L\right), \tag{3.60}$$

$$L\left(\tilde{\tilde{B}}^L\right) = \sqrt{\left(b_1^L - b_2^L\right)^2 + \hat{w}^2_{\tilde{\tilde{B}}^L}} + \sqrt{\left(b_3^L - b_4^L\right)^2 + \hat{w}^2_{\tilde{\tilde{B}}^L}} + \left(b_3^L - b_2^L\right) + \left(b_4^L - b_1^L\right), \tag{3.61}$$

Also, $S\left(\tilde{\tilde{A}}^L, \tilde{\tilde{B}}^L\right) \in [0,1]$.

Calculate the degree of similarity $S\left(\tilde{\tilde{A}}^U, \tilde{\tilde{B}}^U\right)$ between the upper trapezoidal fuzzy numbers $\tilde{\tilde{A}}^U$ and $\tilde{\tilde{B}}^U$, shown as follows:

$$S\left(\tilde{\tilde{A}}^U, \tilde{\tilde{B}}^U\right) = \begin{cases} \left[1 - \dfrac{\sum_{i=1}^{4} \left|a_i^U - b_i^U\right|}{4}\right] \times \dfrac{\min\left(L\left(\tilde{\tilde{A}}^U\right), L\left(\tilde{\tilde{B}}^U\right)\right) + \min\left(\hat{w}_{\tilde{\tilde{A}}^U}, \hat{w}_{\tilde{\tilde{B}}^U}\right)}{\max\left(L\left(\tilde{\tilde{A}}^U\right), L\left(\tilde{\tilde{B}}^U\right)\right) + \max\left(\hat{w}_{\tilde{\tilde{A}}^U}, \hat{w}_{\tilde{\tilde{B}}^U}\right)}, & \text{if } \min\left(\hat{w}_{\tilde{\tilde{A}}^U}, \hat{w}_{\tilde{\tilde{B}}^U}\right) \neq 0, \\ 0, & \text{otherwise.} \end{cases}$$

(3.62)

Here,

$$L\left(\tilde{\tilde{A}}^U\right) = \sqrt{\left(a_1^U - a_2^U\right)^2 + \hat{w}^2_{\tilde{\tilde{A}}^U}} + \sqrt{\left(a_3^U - a_4^U\right)^2 + \hat{w}^2_{\tilde{\tilde{A}}^U}} + \left(a_3^U - a_2^U\right) + \left(a_4^U - a_1^U\right), \tag{3.63}$$

$$L\left(\tilde{\tilde{B}}^U\right) = \sqrt{\left(b_1^U - b_2^U\right)^2 + \hat{w}^2_{\tilde{\tilde{B}}^U}} + \sqrt{\left(b_3^U - b_4^U\right)^2 + \hat{w}^2_{\tilde{\tilde{B}}^U}} + \left(b_3^U - b_2^U\right) + \left(b_4^U - b_1^U\right), \tag{3.64}$$

Also, $S\left(\tilde{\tilde{A}}^U, \tilde{\tilde{B}}^U\right) \in [0,1]$.

<u>Step 5:</u> Calculate the difference $\Delta x$ on the x- axis and the difference $\Delta y$ on the y- axis of the COG points of the interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ shown as follows:

$$\Delta x = \begin{cases} \left|x^*_{\tilde{\tilde{A}}} - x^*_{\tilde{\tilde{B}}}\right|, & \text{if } A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right) \neq 0 \text{ and } A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right) \neq 0, \\ 0, & \text{otherwise.} \end{cases} \tag{3.65}$$

$$\Delta y = \begin{cases} \left|y^*_{\tilde{\tilde{A}}} - y^*_{\tilde{\tilde{B}}}\right|, & \text{if } A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right) \neq 0 \text{ and } A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right) \neq 0, \\ 0, & \text{otherwise.} \end{cases} \tag{3.66}$$

<u>Step 6:</u> Calculate the degree of similarity $S\left(\tilde{\tilde{A}},\tilde{\tilde{B}}\right)$ between the interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ as follows:

$$S\left(\tilde{\tilde{A}},\tilde{\tilde{B}}\right)=\left[\frac{S\left(\tilde{\tilde{A}}^{L},\tilde{\tilde{B}}^{L}\right)+S\left(\tilde{\tilde{A}}^{U},\tilde{\tilde{B}}^{U}\right)}{2}\times(1-\Delta x)\times(1-\Delta y)\right]^{\left(\frac{1}{1+2t}\right)}\times\left(1-\left|\hat{w}_{\tilde{\tilde{A}}}^{U}-\hat{w}_{\tilde{\tilde{B}}}^{U}-\hat{w}_{\tilde{\tilde{A}}}^{L}+\hat{w}_{\tilde{\tilde{B}}}^{L}\right|\right)^{\frac{u}{2}},$$

(3.67)

Here,

$$t=\begin{cases}1, & \text{if } A\left(\tilde{\tilde{A}}^{U}\right)-A\left(\tilde{\tilde{A}}^{L}\right)\neq 0 \text{ and } A\left(\tilde{\tilde{B}}^{U}\right)-A\left(\tilde{\tilde{B}}^{L}\right)\neq 0,\\ 0, & \text{otherwise.}\end{cases} \quad (3.68)$$

$$u=\begin{cases}1, & \text{if } a_1^U=a_4^U \text{ and } b_1^U=b_4^U,\\ 0, & \text{otherwise.}\end{cases} \quad (3.69)$$

Also, $S\left(\tilde{\tilde{A}},\tilde{\tilde{B}}\right)\in[0,1]$. The larger the value of $S\left(\tilde{\tilde{A}},\tilde{\tilde{B}}\right)$, the more the similarity between the interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$.

The aforesaid concept of similarity measure between interval-valued trapezoidal fuzzy numbers has the following properties (Wei and Chen, 2009).

**Property 1**: *When* $\hat{w}_{\tilde{\tilde{A}}}^{U}\neq 0$, *and* $\hat{w}_{\tilde{\tilde{B}}}^{U}\neq 0$, *two interval-valued trapezoidal fuzzy numbers* $\tilde{\tilde{A}}$ *and* $\tilde{\tilde{B}}$ *are identical if and only if* $S\left(\tilde{\tilde{A}},\tilde{\tilde{B}}\right)=1$.

**Property 2**: $S\left(\tilde{\tilde{A}},\tilde{\tilde{B}}\right)=S\left(\tilde{\tilde{B}},\tilde{\tilde{A}}\right)$

**Property 3**: *If* $\tilde{\tilde{A}}$ *and* $\tilde{\tilde{B}}$ *are real values between zero and one, where* $\tilde{\tilde{A}}=a$ *and* $\tilde{\tilde{B}}=b$, *then* $S\left(\tilde{\tilde{A}},\tilde{\tilde{B}}\right)=1-|a-b|$.

### 3.3.6 Division Operator Ø for IV Trapezoidal Fuzzy Numbers

Wei and Chen, (2009) proposed a new division operator for interval-valued trapezoidal fuzzy numbers for fuzzy risk analysis. According to them, given for two fuzzy numbers:

Let $\tilde{\tilde{A}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; \hat{w}_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; \hat{w}_{\tilde{\tilde{A}}}^U\right)\right]$, $\tilde{\tilde{B}} = \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; \hat{w}_{\tilde{\tilde{B}}}^L\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; \hat{w}_{\tilde{\tilde{B}}}^U\right)\right]$,

$$U^L = \left\{ a_1^L/b_1^L, a_2^L/b_2^L, a_3^L/b_3^L, a_4^L/b_4^L \right\}, \; U^U = \left\{ a_1^U/b_1^U, a_2^U/b_2^U, a_3^U/b_3^U, a_4^U/b_4^U \right\}, \tag{3.70}$$

$x^L = \min\left(U^L\right), x^U = \min\left(U^U\right), y^L = \max\left(U^L\right), y^U = \max\left(U^U\right)$, where

$$0 \le a_1^L \le a_2^L \le a_3^L \le a_4^L \le 1,$$
$$0 \le a_1^U \le a_2^U \le a_3^U \le a_4^U \le 1,$$

$$0 \le b_1^L \le b_2^L \le b_3^L \le b_4^L \le 1,$$
$$0 \le b_1^U \le b_2^U \le b_3^U \le b_4^U \le 1.$$

The division operator Ø proposed by (Wei and Chen, 2009) between interval-valued trapezoidal fuzzy numbers has been presented follows:

$$\tilde{\tilde{A}} \varnothing \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; \hat{w}_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; \hat{w}_{\tilde{\tilde{A}}}^U\right)\right] \varnothing \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; \hat{w}_{\tilde{\tilde{B}}}^L\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; \hat{w}_{\tilde{\tilde{B}}}^U\right)\right]$$

$$= \begin{bmatrix} \left(\min\left(U^L\right), \min\left(U^L - x^L\right), \max\left(U^L - y^L\right), \max\left(U^L\right); \min\left(\hat{w}_{\tilde{\tilde{A}}}^L, \hat{w}_{\tilde{\tilde{B}}}^L\right)\right), \\ \left(\min\left(U^U\right), \min\left(U^U - x^U\right), \max\left(U^U - y^U\right), \max\left(U^U\right); \min\left(\hat{w}_{\tilde{\tilde{A}}}^U, \hat{w}_{\tilde{\tilde{B}}}^U\right)\right) \end{bmatrix} \tag{3.71}$$

Here $\left(U^L - x^L\right)$ denotes deleting the element $x^L$ from the set $U^L$, $\left(U^U - x^U\right)$ denotes deleting the element $x^U$ from the set $U^U$, $\left(U^L - y^L\right)$ denotes deleting the element $y^L$ from the set $U^L$, $\left(U^U - y^U\right)$ denotes deleting the element $y^U$ from the set $U^U$.

## 3.4 Performance Appraisement Modeling using Theory of GTFNs

In this section, a fuzzy embedded performance appraisement module has been developed by exploring the concept of Generalized Trapezoidal Fuzzy Numbers (GTFNs) set. An overall SC performance index has been evaluated in terms of fuzzy quantitative measure. The proposed Decision Support System (DSS) also utilizes the concept of fuzzy numbers ranking by 'maximizing set and minimizing set'; and also by 'degree of similarity measure between two fuzzy numbers' in course of identifying ill-performing areas of the particular SC under consideration. Detailed description of the said DSS has been provided below.

### 3.4.1 Procedural Steps

A fuzzy based performance appraisement module proposed in this part of work has been presented below.

It utilizes the concept of Generalized Trapezoidal Fuzzy Numbers (GTFNs) set. General Hierarchy Criteria (GHC) for evaluating overall supply chain performance extent, adapted in this work involves various criterions as well as sub-criterions at different levels. Let us assume the GHC consists of two-level index system; which aims at achieving the target to evaluate overall appraisement index. 1$^{st}$ level consists of four main criterions: Customer Satisfaction Degree $C_1$, Information Sharing Degree $C_2$, Logistics Performance $C_3$, and Financial Performance $C_4$, respectively.

The 2$^{nd}$ level encompasses different sub-criterions under each of the 1$^{st}$ level main criterion. Performance evaluation is to be started at the 2$^{nd}$ level and then extended to the 1$^{st}$ level; and finally the overall performance extent is to be computed. In order to tackle inherent vagueness arising from subjective decision-making information; linguistic data need to be converted into fuzzy numbers to provide a strong mathematic base of the performance evaluation forum thus facilitating clear understanding of the performing supply chain scenario towards effective decision-making. The procedural steps of performance appraisement module, thus proposed in this work, have been listed below.

**Step 1:** Development/adaptation of a criteria hierarchy (appraisement index system) for SC performance assessment. The appraisement index system may be industry specific; it may differ from a particular supply chain to another one. Depending on the type of organizational supply chain employed, management should examine and finalize the criteria-hierarchy before implementing the appraisement module in practice. An expert committee may be constructed (consisting of management practitioners, academicians, executives at different organizational hierarchy) to seat together towards finalizing the assessment criteria hierarchy. The expert team may refer to the literature, perform field visit, and analyze feedback obtained from the consumers for the final settlement of the criteria hierarchy.

**Step 2:** Supply chain performance assessment encounters with subjective evaluation data to be gathered from a group of decision-makers. This invites fuzziness, incompleteness and imprecision in the decision-making. Such kind of uncertainty as well as vagueness can be avoided by proper selection of linguistic scale (*or Likert scale*); on the basis of which decision makers' personal judgment can be obtained. Therefore, Step 2 performs selection of linguistic variables (corresponding linguistic scale) towards assigning priority weights (of individual criteria/attributes as well as sub-attributes) and appropriateness rating (performance extent) corresponding to each evaluation criterions (at highest level of the criteria hierarchy).

**Step 3:** Collection of expert opinion from a selected decision-making group (subjective judgment) in order to express priority weight as well as appropriate rating against each of the evaluation indices.

**Step 4:** Representing decision-makers' linguistic judgments using appropriate fuzzy numbers set.

Subjective data can only be analyzed unless it is transformed into numeric score. However, it is difficult to express decision-makers' subjective opinion by exact numeric score. Therefore, to analyze such a vague entity; it is advised to represent it in terms of fuzzy numbers. Once, linguistic evaluation information is transformed into fuzzy numbers; fuzzy operational rules can easily be applied towards computing an overall performance extent for the said supply chain.

**Step 5:** Use of fuzzy operational rules towards estimating aggregated weight as well as aggregated rating (pulled opinion of the decision-makers) for each of the selection criterion.

**Step 6:** Calculation of overall SC performance index called Fuzzy Performance Index (FPI). Aforesaid computation is to be started at the highest level, and extended towards backward (previous levels) and finally to the $1^{st}$ level. The fuzzy weighted average of performance rating of individual $1^{st}$ level indices gives us the overall FPI for the supply chain under consideration.

Appropriateness rating for each of the 1st level index (criterion) $U_i$ (rating of $i_{th}$ 1st level index) is computed as follows:

$$U_i = \frac{\sum U_{ij} \otimes w_{ij}}{\sum w_{ij}} \qquad (3.72)$$

In this expression, Eq. (3.72) $U_{ij}$ denotes the aggregated fuzzy appropriateness rating against $j_{th}$ sub-criterion (at 2nd level) which is under $i_{th}$ main criterion in the 1st level. Also $w_{ij}$ is the aggregated fuzzy weight against $j_{th}$ sub-criterion (at 2nd level) which is under $i_{th}$ main criterion in 1st level.

The *Fuzzy Performance Index (FPI)* is computed as:

$$U(FPI) = \frac{\sum U_i \otimes w_i}{\sum w_i} \qquad (3.73)$$

In this expression, Eq. (3.73) $U_i$ denotes the computed fuzzy appropriateness rating, obtained using Eq. (3.72) against $i_{th}$ index at 1st level. Also $w_i$ is the aggregated fuzzy priority weight against $i_{th}$ index in 1st level.

**Step 7:** Investigation for identifying ill-performing areas those seek for future improvement. This requires exploration of the concept of fuzzy numbers ranking using '*Maximizing Set and Minimizing Set*'.

At this step, Fuzzy Performance Importance Index (FPII) has been computed for individual sub-criterions (at the 2nd level). FPII encompasses fuzzy aggregated appropriateness rating as well as fuzzy aggregated priority weight of various 2nd level sub-indices. The concept of computing FPII has been proposed by (Lin et al., 2006) towards identifying agile barriers/obstacles in agile supply chain. FPII can be calculated as:

$$FPII = w_{ij}^{'} \otimes U_{ij} \qquad (3.74)$$

Here, $w_{ij}^{'} = (1,1,1,1) - w_{ij}$ (3.75)

The concept of fuzzy numbers ranking using '*Maximizing Set and Minimizing Set*' has been explored to compute total utility value $U_T^{\alpha}$ corresponding to FPII of individual sub-criterions at 2nd level. The term $\alpha$ represents the index of optimism. In this computation three types of decision-making attitude can be articulated. When $\alpha$ is 0.5, the decision-making group is said to be risk averter; $\alpha$ is 0.0, the decision-making group is said to be neutral, and $\alpha$ is 1.0, representing the decision-making group to be risk lover. The total utility value can be considered as the crisp performance representative against individual sub-indices at 2nd level. Higher value of total utility indicates a higher degree of satisfactory performance conformance. By utilizing this concept, 2nd level sub-criterions can be ranked. A higher utility value yields upper ranking order. By this way, ill-performing areas (sub-indices) can easily be identified; these areas require special managerial care for future improvement which in turn may boost up overall performance extent of the said supply chain, under consideration.

However, aforesaid approach is quite common; and well documented in literature with major applications to identify obstacles in agile/lean supply chain. The same concept can also be fruitfully adapted in the context of supply chain overall performance appraisement.

The '*Degree of Similarity*' (between two fuzzy numbers), is a concept in which two fuzzy numbers can easily be compared. This similarity extent may vary from 0 to 1. Adaptation of this concept has been proposed in this research as an alternative way to search for ill-performing areas in the supply chain. From the data set containing FPII values of individual sub-criterions at 2nd level; an ideal FPII $\left(FPII_{Ideal}\right)$ has been found out. The degree of similarity (DOS) between $\left(FPII_{Ideal}\right)$ and individual FPIIs (of different sub-criterions at 2nd level) has thus been computed. A sub-criterion which corresponds to highest degree of similarity value is assumed to contribute maximum to the overall performance extent. Based on computed DOS values, individual sub-criterions have been ranked and also ill-performing sub-indices have been sorted out accordingly. A variety of formulae were proposed by pioneer researchers (Chen, 1996; Hsieh and Chen, 1999; Chen and Chen, 2003; Yong et al., 2004; Chen, 2006; Sridevi and Nadarajan, 2009) in course of computing DOS between two fuzzy numbers. In this research, those formulae have been utilized and a comparison has been made on computed DOS values as well as performance ranking order of different sub-criterions at 2nd level of the particular SC hierarchy.

### 3.4.2 Case Study

A case study has been conducted in a famous automobile manufacturing company located at Tamil Nadu, India. The company's footprint in India has been growing steadily since its inception in 2005. Marked by an impressive rise in sales, award-winning quality from locally-built products, an expanding range of innovative cars and a rapidly evolving dealer network, the growth underlines the strategic importance of India to the said company. Guided by its global Brand commitment 'Innovation and Excitement for Everyone' the company delivers cutting-edge technology, Innovative design and a rewarding experience to all its customers. In India, the company has been constantly expanding innovative and exciting product offerings across hatchback, sports car, SUV and sedan segments.

The case study is mainly based on the questionnaire survey to various levels of management authorities such as managers, executive engineers and supervisors from different departments of the said company; the group has been considered as the panel of decision makers (experts). They all are well educated (possessing minimum bachelor degree) and all are having at least 5 year of experience in the concerned firm. The questionnaire has been prepared considering various aspects for SC performance dimensions (or indices), separately. As human decision making often encounters some kind of imprecision, ambiguity as well as vague information. In order to avoid these, the linguistic variable has been used for expert data collection.

To precede the evaluation of SC performance indices, initially the assessment team has been formed and then the prepared questionnaire has been circulated to the decision makers (respondents) asking for their opinion. The decision makers have provided expert judgment in linguistic terms. For the analysis purpose, fuzzy set theory has been adopted and these linguistic variables have further converted into appropriate fuzzy numbers. Finally, based on fuzzy operational rules, expert data have been analyzed.

The two-level criteria hierarchy for supply chain performance evaluation adopted in this study has been furnished in Table 3.1 (Tao, 2009). The definitions of various SC performance indices (as indicated in Table 3.1) have been furnished in the Appendix B (at the end of the dissertation). Table 3.2 represents five-member linguistic terms (and their corresponding fuzzy representations) for analyzing decision making information. In order to provide priority weight against various criteria and sub-criteria at different level; the decision-making group has been instructed to use the following linguistic terms: **Very Low (VL)**, **Low (L)**, **Medium (M)**, **High (H)**, and **Very High (VH)**. The following linguistic scale has been utilized to assign performance extent (appropriateness rating) against individual 2$^{nd}$ level sub-indices: **Very Poor (VP)**, **Poor (P)**, **Satisfactory (S)**, **Impressive (I)**, **Extremely Impressive (EI)**.

Real world decision making problems are too complex due to subjectivity and multi-possibility of evaluation data. Hence, decision making relies on subjective human judgment. The information collected from a group of experts (Decision Makers) expressed in linguistic terms are often vague in nature. The ambiguity and vagueness which is inherently present with subjective evaluation information cannot be tackled by traditional tools and techniques. Here, the application potential of fuzzy/grey numbers set theory deserves mention. In fuzzy based decision making, subjective data (linguistic variables) are converted into appropriate fuzzy numbers based on a predefined scale, as it has been used in this work (Table 3.2).

Assuming a decision-making group consists of five decision makers (DMs): DM1, DM2, DM3, DM4, and DM5. Assume that appropriateness rating (in linguistic scale) of 2$^{nd}$ level sub-indices assigned by DMs given in Table 3.3. Priority weights (in linguistic scale) of 2$^{nd}$ level indices as well as 1$^{st}$ level indices assigned by DMs have been given in Tables (3.4-3.5), respectively. Linguistic decision making information has been transformed into GTFNs. Aggregated fuzzy appropriateness rating and aggregated fuzzy priority weight of 2$^{nd}$ level sub-indices have been computed and shown in Table 3.6. Computed fuzzy appropriateness rating (computed using Eq. 3.72) and aggregated fuzzy priority weight of individual 1$^{st}$ level main indices has been furnished in Table 3.7.

Overall SC performance extent (Fuzzy Performance Index) has been computed using Eq. (3.73); thus becomes: **FPI= (0.173, 0.349, 0.785, 1.559)**

After evaluating FPI, the next step is to rank different 2$^{nd}$ level indices in accordance with their FPII. Thus, ill-performing areas can easily be sorted out and future improvement opportunities can be identified. Computed values of FPII against individual 2$^{nd}$ level sub-indices have been shown in Table 3.8. The concept of ranking fuzzy numbers using '*Maximizing set and Minimizing Set*' has been explored towards evaluating performance ranking order of 2$^{nd}$ level sub-indices in accordance with their total utility degree $\left(U_T^{\alpha}\right)$. Table 3.9 shows ranking order of 2$^{nd}$ level sub-indices for three cases: pessimistic, moderate and optimistic $(\alpha = 0, 0.5, 1)$ decision making group.

Apart from this, the study introduces a new approach to identify ill-performing areas of supply chain. The concept of '*Fuzzy Degree of Similarity*' between individual FPII (of different 2$^{nd}$ level sub-indices) and $\text{FPII}_{\text{Ideal}}$ has been proposed as crisp representative of different 2$^{nd}$ level sub-indices. **$\text{FPII}_{\text{Ideal}}$ thus obtained: (0.270, 0.236, 0.180, 0.127)**

Based on the value of DOS, various 2$^{nd}$ level sub-indices have been ranked. In order to compute fuzzy DOS between two GTFNs, the formulae provide by (Chen, 1996; Hsieh and

Chen, 1999; Chen and Chen, 2003; Yong et al., 2004; Chen, 2006; Sridevi and Nadarajan, 2009) have been explored and ranking order of sub-indices has been obtained (Table 3.10). This facilitates in realizing ill-performing areas of the said supply chain. The data obtained thereof, exhibits compatible result in exploring DOS concept (as an alternative of total utility degree) towards 2$^{nd}$ level sub-criteria ranking, thereby identifying ill-performing areas of the supply chain.

## 3.5 Performance Appraisement Modeling using Theory of GIVFNs

In this section, a fuzzy embedded performance evaluation platform has been developed by exploring the concept of Generalized Interval-Valued Fuzzy Numbers (GIVFNs) set. An overall SC performance index has been evaluated in terms of fuzzy quantitative measure. The proposed Decision Support System (DSS) also utilizes the concept of fuzzy numbers ranking by 'degree of similarity measure between two Interval-Valued Fuzzy Numbers (IVFNs)' in course of identifying ill-performing areas of the particular SC under consideration. Detailed description of the said DSS has been provided below.

### 3.5.1 Procedural Steps

In this section, a fuzzy based performance appraisement module has been proposed using the concept of generalized Interval-Valued Fuzzy Numbers (IVFNs) set. Let us assume the General Hierarchy Criteria (GHC) consists of four-level index system; which aims at achieving the target to evaluate overall appraisement index. 1$^{st}$ level consists of five main criterions: Supply $C_1$, Inbound Logistics $C_2$, Core Manufacturing $C_3$, Outbound Logistics $C_4$, and Marketing & Sales $C_5$, respectively.

Performance evaluation is to be started at the 4$^{th}$ level and then extended to the 1$^{st}$ level; and finally the overall performance extent is to be computed. The procedural steps of performance appraisement have been more or less same as mentioned before, only the difference is with the computational part towards measuring overall performance extent as well as in identifying supply chain network's ill-performing areas; as this model explores generalized Interval-Valued Fuzzy Numbers (IVFNs) set which is somewhat different from the theory of GTFNs set used in empirical study reported in Section 3.4.

**Step 1:** Selection of linguistic variables towards assigning priority weights (of individual criteria/attributes as well as sub-attributes) and appropriateness rating (performance extent) corresponding to each evaluation criterions (at highest level of the criteria hierarchy).
**Step 2:** Collection of expert opinion from a selected decision making group (subjective judgment) in order to express priority weight as well as appropriate rating against each of the evaluation indices.
**Step 3:** Representing decision makers' linguistic judgments using appropriate fuzzy numbers set.
**Step 4:** Use of fuzzy operational rules towards estimating aggregated weight as well as aggregated rating (pulled opinion of the decision-makers) for each of the selection criterion.
**Step 5:** Calculation of overall SC performance index called Fuzzy Performance Index (FPI). Aforesaid computation is to be started at the 4th level, and extended towards backward (previous levels) and finally to the 1st level. The fuzzy weighted average of performance rating of individual 1st level indices gives us the overall FPI for the supply chain under consideration.
Consider a four-level GHC consisting of a total of $m$ main criteria at 1st level. Each 1st level main criterion contains a total of $n$ criteria at 2nd level. Each 2nd level criterion contains a total of $o$ criteria at 3rd level and each 3rd level main criterion contains a total of $p$ sub-criteria at 4th level.

In this model, assume that,

$i = 1,2,...,m;$

$j = 1,2,...,n;$

$k = 1,2,...,o;$

$l = 1,2,...,p.$

Appropriateness rating for each of the 3rd level index $U_{ijk}$ (rating of $k_{th}$ 3rd level index) has been computed as follows:

$$U_{ijk} = \frac{\sum U_{ijkl} \otimes w_{ijkl}}{\sum w_{ijkl}} \tag{3.76}$$

$$U_{ijk} = \frac{\sum_{l=1}^{p} U_{ijkl} \otimes w_{ijkl}}{\sum_{l=1}^{p} w_{ijkl}}$$

In this expression, Eq. (3.76) $U_{ijkl}$ denotes the aggregated fuzzy appropriateness rating against $l_{th}$ sub-criterion (at 4th level). Also $w_{ijkl}$ is the aggregated fuzzy weight against $l_{th}$ sub-criterion (at 4th level).

Appropriateness rating for each of the 2nd level index $U_{ij}$ (rating of $j_{th}$ 2nd level index) is computed as follows:

$$U_{ij} = \frac{\sum U_{ijk} \otimes w_{ijk}}{\sum w_{ijk}} \quad (3.77)$$

$$U_{ij} = \frac{\sum_{k=1}^{o} U_{ijk} \otimes w_{ijk}}{\sum_{k=1}^{o} w_{ijk}}$$

In this expression, Eq. (3.77) $U_{ijk}$ denotes the aggregated fuzzy appropriateness rating against $k_{th}$ sub-criterion (at 3rd level) which is under $j_{th}$ criterion at 2nd level and $i_{th}$ main criterion in the 1st level. Also $w_{ijk}$ is the aggregated fuzzy weight against $k_{th}$ sub-criterion (at 3rd level).

Appropriateness rating for each of the 1st level index $U_i$ (rating of $i_{th}$ 1st level index) is computed as follows:

$$U_{i} = \frac{\sum U_{ij} \otimes w_{ij}}{\sum w_{ij}} \quad (3.78)$$

$$U_{i} = \frac{\sum_{j=1}^{n} U_{ij} \otimes w_{ij}}{\sum_{j=1}^{n} w_{ij}}$$

In this expression, Eq. (3.78) $U_{ij}$ denotes the aggregated fuzzy appropriateness rating against $j_{th}$ sub-criterion (at 2$^{nd}$ level) which is under $i_{th}$ main criterion in the 1$^{st}$ level. Also $w_{ij}$ is the aggregated fuzzy weight against $j_{th}$ sub-criterion (at 2$^{nd}$ level) which is under $i_{th}$ main criterion in 1$^{st}$ level.

The *Fuzzy Performance Index (FPI)* can be computed as:

$$U(FPI) = \frac{\sum U_i \otimes w_i}{\sum w_i} \tag{3.79}$$

$$U(FPI) = \frac{\sum_{i=1}^{m} U_i \otimes w_i}{\sum_{i=1}^{m} w_i}$$

In this expression, Eq. (3.79) $U_i$ denotes the computed fuzzy appropriateness rating; obtained using Eq. (3.78), against $i_{th}$ index at 1$^{st}$ level. Also $w_i$ is the aggregated fuzzy priority weight against $i_{th}$ index in 1$^{st}$ level.

**Step 6:** Investigation for identifying ill-performing areas those seek for future improvement.

At this step, Fuzzy Performance Importance Index (FPII) needs to be computed for individual sub-criterions (at the 4$^{th}$ level).

$$FPII = w'_{ijkl} \otimes U_{ijkl} \tag{3.80}$$

$$\left[ [(1,1,1,1;1)(1,1,1,1;1)] - w_{ijkl} \right] = w'_{ijkl} \tag{3.81}$$

The '*Degree of Similarity*' (between two fuzzy numbers) concept has been proposed here to identify ill-performing areas in the supply chain. From the data set containing FPII values of individual sub-criterions at 4$^{th}$ level; an ideal FPII $(FPII_{Ideal})$ has been found out. The degree of similarity (DOS) between $(FPII_{Ideal})$ and individual FPIIs (of different sub-criterions at 4$^{th}$ level) has thus been computed. A sub-criterion which corresponds to highest degree of similarity is assumed to contribute maximum to the overall performance extent. Based on computed DOS values, individual sub-criterions have been ranked and also ill-performing sub-indices have been identified accordingly.

### 3.5.2 Empirical Data Analyses

The four-level criteria hierarchy for supply chain performance evaluation adopted in this study has been furnished in Table 3.11 (Chan and Qi, 2003). The definitions of various SC performance indices (as indicated in Table 3.11) have been furnished in the Appendix C (at the end of the dissertation). Table 3.12 represents nine-member linguistic terms (and their corresponding interval-valued fuzzy representations) for analyzing decision-making information. In order to provide priority weight against various criteria and sub-criteria at different level; the decision-making group has been instructed to use the following linguistic terms: **Absolutely Low (AL)**, **Very Low (VL)**, **Low (L)**, **Fairly Low (FL)**, **Medium (M)**, **Fairly High (FH)**, **High (H)**, **Very High (VH)** and **Absolutely High (AH)**. The following linguistic scale has been utilized to assign performance extent (appropriateness rating) against individual 4$^{th}$ level sub-indices: **Absolutely Poor** (**AP)**, **Very Poor (VP)**, **Poor (P)**, **Fairly Poor (FP)**, **Medium (M)**, **Fairly Satisfactory (FS)**, **Satisfactory (S)**, **Very Impressive (VI)**, **Absolutely Impressive (AI)**. Assuming a decision-making group consists of five decision-makers (DMs): DM1, DM2, DM3, DM4, and DM5. Assume that appropriateness rating (in linguistic scale) of 4$^{th}$ level indices assigned by DMs given in Table 3.13. Priority weight (in linguistic scale) of 4$^{th}$ level indices, 3$^{rd}$ level indices, 2$^{nd}$ level indices and finally 1$^{st}$ level indices assigned by DMs have been given in Tables (3.14-3.17), respectively. Linguistic decision-making information has been transformed into GIVFNs. Aggregated fuzzy appropriateness rating and aggregated fuzzy priority weight of 4$^{th}$ level indices have been computed and shown in Table 3.18. Computed fuzzy appropriateness rating and aggregated fuzzy priority weight of 3$^{rd}$ level indices have been furnished in Table 3.19. Table 3.20 represents computed fuzzy appropriateness rating and aggregated fuzzy priority weight of 2$^{nd}$ level indices. Computed fuzzy appropriateness rating and aggregated fuzzy priority weight of 1$^{st}$ level indices have been computed and presented in Table 3.21.

Overall SC performance extent (Fuzzy Performance Index) thus becomes:

**FPI= [(0.647, 0.746, 0.1.027, 1.176; 0.5) (0.0.516, 0.644, 1.238, 1.508; 1)]**

After evaluating FPI, the next step is to rank different 4$^{th}$ level indices in accordance with their FPII. Thus, ill-performing areas can easily be sorted out and future improvement opportunities can be identified. Computed values of FPII against individual 4th level sub-indices have been shown in Table 3.22. $FPII_{Ideal}$ thus obtained:

$$\mathbf{FPII_{Ideal} = [(0.263, 0.303, 0.394, 0.599; 0.5)\ (0.189, 0.254, 0.443, 0.517; 1)]}$$

The degree of similarity between individual FPIIs and $FPII_{Ideal}$ has been computed and tabulated in Table 3.23. Based on the DOS value individual sub-criterions (sub-indices) have been ranked (Table 3.23).

## 3.6 Managerial Implications

Supply chain management is the main model of corporate production, operation and market competition. Performance evaluation of supply chain provides important and strategic guidance for the effective implementation and related decision-making of supply chain management. The foregoing work demonstrates fuzzy embedded feasible appraisement platforms for analyzing existing supply chain performance; this creates an opportunity to use across a variety of supply chain situations and thus generate a systematic and logical evaluation forum for comparison and benchmarking of different supply chain scenarios across different industries. Supply chain construct (criteria hierarchy) may vary from industry to industry (food industry, service industry, chemical, automotive etc.). This aspect has been referred here as 'different supply chain situations and scenarios'.

Based on the analyzed results, the managers can find out the problems (ill-performing areas) and improve organizational supply chain performance. Proposed fuzzy based performance assessment approaches are seemed innovative and create a new way for other disciplines. This study provides a practical and easy-to-use model that enables senior and top management decision-makers as well as operation managers involved in the supply chain to assess, compare, and take anticipatory action so that the supply chain can experience improvement in a timesaving and effective manner and achieve excellence in future performance.

## 3.7 Concluding Remarks

The article addresses the issues of Supply Chain (SC) performance evaluation; the process of assessing effectiveness of the existing SC. The research is based on a review of the current understanding of supply chain management and literature related to supply chain performance assessment. This study delivers different frameworks for supply chain performance measurement in fuzzy context. Empirical data has been analyzed to provide a clear understanding of the procedural steps to be followed in implementing proposed appraisement modules. The main contributions of this research have been summarized below.

1. Introduction to fuzzy embedded performance appraisement modules analyzing decision-makers' linguistic evaluation information.
2. Exploration of integrated criteria hierarchy consisting of various main criteria/indices as well as sub-criteria/sub-indices to understand the basis of the appraisement index system.
3. Exploration of GTFNs as well as GIVFNs set theories to analyze subjective evaluation information (performance appropriateness rating as well as priority weights).
4. Scope for identifying ill-performing areas of the supply chain.
5. Apart from using the theory of fuzzy numbers ranking by '*Maximizing Set and Minimizing Set*' (used in ranking of generalized fuzzy numbers); the study proposes exploration of the concept '*Fuzzy Degree of Similarity*' in course of identifying ill-performing areas in the supply chain.

Table 3.1: Evaluation Index System of Supply Chain Performance

| Goal | $1^{st}$ level indices | $2^{nd}$ level indices |
|---|---|---|
| Evaluation Index of Supply Chain Performance, C | Customer Satisfaction Degree, $C_1$ | Order Fulfillment Rate, $C_{11}$ |
| | | Rate of Maintaining Customers, $C_{12}$ |
| | | On-Time Delivery, $C_{13}$ |
| | | Product Quality, $C_{14}$ |
| | Information Sharing Degree, $C_2$ | Unit Information Cost, $C_{21}$ |
| | | Timeliness of Information Transmission, $C_{22}$ |
| | | Accuracy of Information Transmission, $C_{23}$ |
| | | Utilization Rate of Information, $C_{24}$ |
| | Logistics Performance, $C_3$ | Transport Loss Rate, $C_{31}$ |
| | | Utilization Rate of Warehouse, $C_{32}$ |
| | | Stock Turnover Rate, $C_{33}$ |
| | | Full-Load Ratio of Transportation, $C_{34}$ |
| | Financial Performance, $C_4$ | Profit-to-Cost Ratio, $C_{41}$ |
| | | Profit Growth Rate, $C_{42}$ |
| | | Return on Net Worth, $C_{43}$ |
| | | Capital Maintenance and Increment Ratio, $C_{44}$ |

Table 3.2: Five-member linguistic terms and their corresponding fuzzy numbers

| Linguistic terms for weight assignment | Linguistic terms for ratings | Generalized trapezoidal fuzzy numbers |
|---|---|---|
| Very Low, VL | Very Poor, VP | (0, 0, 0.125, 0.25) |
| Low, L | Poor, P | (0.125, 0.25, 0.375, 0.5) |
| Medium, M | Satisfactory, S | (0.375, 0.5, 0.5, 0.625) |
| High, H | Impressive, I | (0.5, 0.625, 0.75, 0.875) |
| Very High, VH | Extremely Impressive, EI | (0.75, 0.875, 1, 1) |

Table 3.3: Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs

| 2nd level indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | I | I | EI | EI | I |
| $C_{12}$ | S | S | I | I | S |
| $C_{13}$ | S | EI | I | I | I |
| $C_{14}$ | S | S | S | S | S |
| $C_{21}$ | P | S | P | S | S |
| $C_{22}$ | P | S | S | S | S |
| $C_{23}$ | I | S | S | S | S |
| $C_{24}$ | P | S | P | P | P |
| $C_{31}$ | S | I | I | I | S |
| $C_{32}$ | S | S | S | S | I |
| $C_{33}$ | I | I | S | I | I |
| $C_{34}$ | P | P | S | P | P |
| $C_{41}$ | S | S | S | S | I |
| $C_{42}$ | P | P | S | S | P |
| $C_{43}$ | I | I | I | I | S |
| $C_{44}$ | S | S | S | S | S |

Table 3.4: Priority weight (in linguistic scale) of 2nd level indices assigned by DMs

| 2nd level indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | H | H | H | VH | H |
| $C_{12}$ | H | M | H | H | H |
| $C_{13}$ | VH | VH | M | H | VH |
| $C_{14}$ | H | H | H | H | H |
| $C_{21}$ | H | H | VH | VH | H |
| $C_{22}$ | H | M | H | H | H |
| $C_{23}$ | VH | H | M | VH | VH |
| $C_{24}$ | H | H | H | H | H |
| $C_{31}$ | H | H | VH | VH | H |
| $C_{32}$ | H | M | H | H | H |
| $C_{33}$ | VH | H | H | VH | H |
| $C_{34}$ | H | M | H | H | H |
| $C_{41}$ | VH | H | M | VH | VH |
| $C_{42}$ | H | H | VH | H | H |
| $C_{43}$ | H | H | H | VH | H |
| $C_{44}$ | H | M | H | H | H |

Table 3.5: Priority weight (in linguistic scale) of 1st level indices assigned by DMs

| 1st level indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_1$ | VH | H | VH | VH | H |
| $C_2$ | H | M | H | H | H |
| $C_3$ | VH | H | VH | VH | VH |
| $C_4$ | H | H | M | H | H |

Table 3.6: Aggregated fuzzy appropriateness rating and aggregated fuzzy priority weight of 2nd level sub-indices

| 2nd level indices | Aggregated fuzzy appropriateness rating | Aggregated fuzzy priority weight |
|---|---|---|
| $C_{11}$ | (0.600,0.725,0.850,0.925) | (0.550,0.675,0.800,0.900) |
| $C_{12}$ | (0.425,0.550,0.600,0.725) | (0.475,0.600,0.700,0.825) |
| $C_{13}$ | (0.525,0.650,0.750,0.850) | (0.925,0.750,0.850,0.900) |
| $C_{14}$ | (0.375,0.500,0.500,0.625) | (0.500,0.625,0.750,0.875) |
| $C_{21}$ | (0.275,0.400,0.450,0.575) | (0.600,0.725,0.850,0.925) |
| $C_{22}$ | (0.325,0.450,0.475,0.360) | (0.475,0.600,0.700,0.825) |
| $C_{23}$ | (0.400,0.525,0.550,0.675) | (0.925,0.750,0.850,0.900) |
| $C_{24}$ | (0.175,0.300,0.400,0.525) | (0.500,0.625,0.750,0.875) |
| $C_{31}$ | (0.450,0.575,0.650,0.775) | (0.600,0.725,0.850,0.925) |
| $C_{32}$ | (0.400,0.525,0.550,0.675) | (0.475,0.600,0.700,0.825) |
| $C_{33}$ | (0.475,0.600,0.700,0.825) | (0.600,0.725,0.850,0.925) |
| $C_{34}$ | (0.175,0.300,0.400,0.525) | (0.475,0.600,0.700,0.825) |
| $C_{41}$ | (0.400,0.525,0.550,0.675) | (0.925,0.750,0.850,0.900) |
| $C_{42}$ | (0.225,0.350,0.425,0.550) | (0.550,0.675,0.800,0.900) |
| $C_{43}$ | (0.475,0.600,0.700,0.825) | (0.550,0.675,0.800,0.900) |
| $C_{44}$ | (0.375,0.500,0.500,0.625) | (0.475,0.600,0.700,0.825) |

Table 3.7: Computed fuzzy appropriateness rating and aggregated fuzzy priority weight of 1st level indices

| 1st level indices | Computed fuzzy appropriateness rating | Aggregated fuzzy priority weight |
|---|---|---|
| $C_1$ | (0.344,0.522,0.797,1.119) | (0.625,0.775,0.900,0.950) |
| $C_2$ | (0.220,0.362,0.549,0.758) | (0.475,0.600,0.700,0.825) |
| $C_3$ | (0.236,0.434,0.484,1.148) | (0.700,0.825,0.950,0.975) |
| $C_4$ | (0.265,0.424,0.636,0.944) | (0.475,0.600,0.700,0.825) |

Table 3.8: Computation of FPII

| $2^{nd}$ level indices | $w_{ij}^{'}$ | $FPII = w_{ij}^{'} \otimes U_{ij}$ |
|---|---|---|
| $C_{11}$ | (0.450,0.325,0.200,0.100) | (0.270,0.236,0.170,0.093) |
| $C_{12}$ | (0.525,0.400,0.300,0.175) | (0.223,0.220,0.180,0.127) |
| $C_{13}$ | (0.075,0.250,0.150,0.100) | (0.039,0.163,0.113,0.085) |
| $C_{14}$ | (0.500,0.375,0.250,0.125) | (0.188,0.188,0.125,0.078) |
| $C_{21}$ | (0.400,0.275,0.150,0.075) | (0.110,0.110,0.068,0.043) |
| $C_{22}$ | (0.525,0.400,0.300,0.175) | (0.171,0.180,0.143,0.063) |
| $C_{23}$ | (0.075,0.250,0.150,0.100) | (0.030,0.131,0.083,0.068) |
| $C_{24}$ | (0.500,0.375,0.250,0.125) | (0.088,0.113,0.100,0.066) |
| $C_{31}$ | ( 0.400,0.275,0.150,0.075) | (0.180,0.158,0.098,0.058) |
| $C_{32}$ | (0.525,0.400,0.300,0.175) | (0.210,0.210,0.165,0.118) |
| $C_{33}$ | (0.400,0.275,0.150,0.075) | (0.190,0.195,0.105,0.062) |
| $C_{34}$ | (0.525,0.400,0.300,0.175) | (0.092,0.120,0.120,0.092) |
| $C_{41}$ | (0.075,0.250,0.150,0.100) | (0.030,0.131,0.083,0.068) |
| $C_{42}$ | (0.450,0.325,0.200,0.100) | (0.101,0.114,0.085,0.055) |
| $C_{43}$ | (0.450,0.325,0.200,0.100) | (0.214,0.195,0.140,0.083) |
| $C_{44}$ | (0.525,0.400,0.300,0.175) | (0.197,0.200,0.150,0.109) |

Table 3.9: Ranking order of 2nd level sub-indices

| 2nd level indices | $U_T^{\alpha=0}$ | Ranking Order | $U_T^{\alpha=0.5}$ | Ranking Order | $U_T^{\alpha=1}$ | Ranking Order |
|---|---|---|---|---|---|---|
| $C_{11}$ | 2.555 | 1 | 2.279 | 1 | 1.894 | 1 |
| $C_{12}$ | 1.976 | 2 | 1.790 | 2 | 1.498 | 2 |
| $C_{13}$ | 0.122 | 16 | 0.424 | 14 | 0.632 | 9 |
| $C_{14}$ | 1.626 | 6 | 1.218 | 7 | 0.710 | 8 |
| $C_{21}$ | 0.825 | 10 | 0.535 | 13 | 0.205 | 16 |
| $C_{22}$ | 1.507 | 8 | 1.385 | 6 | 1.206 | 4 |
| $C_{23}$ | 0.255 | 15 | 0.359 | 16 | 0.392 | 14 |
| $C_{24}$ | 0.737 | 13 | 0.644 | 11 | 0.528 | 10 |
| $C_{31}$ | 1.484 | 9 | 0.988 | 9 | 0.415 | 12 |
| $C_{32}$ | 1.856 | 3 | 1.602 | 3 | 1.236 | 3 |
| $C_{33}$ | 1.593 | 7 | 1.078 | 8 | 0.483 | 11 |
| $C_{34}$ | 0.809 | 11 | 0.809 | 10 | 0.809 | 7 |
| $C_{41}$ | 0.255 | 14 | 0.359 | 15 | 0.392 | 13 |
| $C_{42}$ | 0.804 | 12 | 0.604 | 12 | 0.363 | 15 |
| $C_{43}$ | 1.848 | 4 | 1.434 | 5 | 0.927 | 6 |
| $C_{44}$ | 1.738 | 5 | 1.439 | 4 | 1.024 | 5 |

Table 3.10: Ranking order of $2^{nd}$ level sub-indices using fuzzy degree of similarity

| $2^{nd}$ level indices | DOS by Chen, 1996 | Ranking Order | DOS by Hsieh and Chen, 1999 | Ranking Order | DOS by Chen and Chen, 2003 | Ranking Order |
|---|---|---|---|---|---|---|
| $C_{11}$ | 0.989 | 1 | 0.991 | 1 | 0.972 | 1 |
| $C_{12}$ | 0.984 | 2 | 0.987 | 2 | 0.967 | 2 |
| $C_{13}$ | 0.897 | 10 | 0.915 | 10 | 0.304 | 14 |
| $C_{14}$ | 0.941 | 5 | 0.947 | 6 | 0.848 | 8 |
| $C_{21}$ | 0.879 | 13 | 0.893 | 15 | 0.740 | 12 |
| $C_{22}$ | 0.936 | 6 | 0.945 | 7 | 0.881 | 5 |
| $C_{23}$ | 0.875 | 14 | 0.895 | 15 | 0.227 | 15 |
| $C_{24}$ | 0.888 | 11 | 0.902 | 12 | 0.772 | 10 |
| $C_{31}$ | 0.920 | 8 | 0.926 | 9 | 0.839 | 9 |
| $C_{32}$ | 0.973 | 3 | 0.975 | 3 | 0.923 | 3 |
| $C_{33}$ | 0.927 | 7 | 0.932 | 8 | 0.859 | 7 |
| $C_{34}$ | 0.903 | 9 | 0.914 | 11 | 0.686 | 13 |
| $C_{41}$ | 0.875 | 15 | 0.895 | 14 | 0.227 | 16 |
| $C_{42}$ | 0.886 | 12 | 0.899 | 13 | 0.753 | 11 |
| $C_{43}$ | 0.955 | 4 | 0.958 | 5 | 0.918 | 4 |
| $C_{44}$ | 0.961 | 16 | 0.964 | 4 | 0.878 | 6 |

Table 3.10 (Continued)

| $2^{nd}$ level indices | DOS by Yong et al., 2004 | Ranking Order | DOS by Chen, 2006 | Ranking Order | DOS by Sridevi and Nadarajan, 2009 | Ranking Order |
|---|---|---|---|---|---|---|
| $C_{11}$ | 0.722 | 9 | 0.979 | 1 | 0.224 | 1 |
| $C_{12}$ | 0.814 | 8 | 0.975 | 2 | 0.215 | 2 |
| $C_{13}$ | 0.373 | 13 | 0.338 | 15 | 0.015 | 13 |
| $C_{14}$ | 0.852 | 3 | 0.875 | 9 | 0.120 | 6 |
| $C_{21}$ | 0.546 | 12 | 0.799 | 13 | 0.007 | 14 |
| $C_{22}$ | 0.849 | 4 | 0.936 | 4 | 0.114 | 7 |
| $C_{23}$ | 0.213 | 14 | 0.873 | 10 | 0.000 | 15 |
| $C_{24}$ | 0.607 | 10 | 0.826 | 11 | 0.023 | 11 |
| $C_{31}$ | 0.846 | 5 | 0.882 | 8 | 0.082 | 9 |
| $C_{32}$ | 0.830 | 6 | 0.935 | 5 | 0.185 | 3 |
| $C_{33}$ | 0.942 | 1 | 0.899 | 6 | 0.097 | 8 |
| $C_{34}$ | 0.000 | 16 | 0.720 | 14 | 0.042 | 10 |
| $C_{41}$ | 0.213 | 15 | 0.255 | 16 | 0.000 | 16 |
| $C_{42}$ | 0.577 | 11 | 0.808 | 12 | 0.018 | 12 |
| $C_{43}$ | 0.857 | 2 | 0.945 | 3 | 0.153 | 5 |
| $C_{44}$ | 0.827 | 7 | 0.894 | 7 | 0.157 | 4 |

Table 3.11: Supply Chain Performance Appraisement Modeling

| Goal, C | 1st level indices, $C_i$ | 2nd level indices, $C_{ij}$ | 3rd level indices, $C_{ijk}$ | 4th level indices, $C_{ijkl}$ |
|---|---|---|---|---|
| Supply Chain Performance, C | Supplying, $C_1$ | P & C Design, $C_{11}$ | P & C Design, $C_{111}$ | P & C Design, $C_{1111}$ |
| | | P & C Fabrication, $C_{12}$ | P & C Fabrication, $C_{121}$ | P & C Fabrication, $C_{1211}$ |
| | | Delivery, $C_{13}$ | Delivery Cost, $C_{131}$ | Delivery Cost, $C_{1311}$ |
| | | | Delivery Reliability, $C_{132}$ | Timeliness, $C_{1321}$ |
| | | | | Error-Free,$C_{1322}$ |
| | | | Delivery Flexibility, $C_{133}$ | Frequency,$C_{1331}$ |
| | | | | Amount,$C_{1332}$ |
| | Inbound Logistics, $C_2$ | Supply Base Management, $C_{21}$ | Supply Base Management, $C_{211}$ | Supply Base Management, $C_{2111}$ |
| | | Transportation, $C_{22}$ | Transport Cost, $C_{221}$ | Transport Cost, $C_{2211}$ |
| | | | Transport Productivity, $C_{222}$ | Transport Productivity, $C_{2221}$ |
| | | | Transport Flexibility, $C_{223}$ | Transport Flexibility, $C_{2231}$ |
| | | | Facility Utilization, $C_{224}$ | Facility Utilization,$C_{2241}$ |
| | | Receiving and Inspection, $C_{23}$ | Receiving and Inspection, $C_{231}$ | Receiving and Inspection, $C_{2311}$ |
| | | Handling and Storing, $C_{24}$ | Handling and Storing, $C_{241}$ | Handling and Storing, $C_{2411}$ |
| | Core Manufacturing, $C_3$ | Internal Manufacture Operations, $C_{31}$ | Product Quality, $C_{311}$ | Product Quality, $C_{3111}$ |
| | | | Operation Costs, $C_{312}$ | Operation Costs, $C_{3121}$ |
| | | | Efficiency, $C_{313}$ | Efficiency, $C_{3131}$ |
| | | | Flexibility, $C_{314}$ | Flexibility, $C_{3141}$ |
| | | | Productivity, $C_{315}$ | Productivity,$C_{3151}$ |
| | | Research and Development, $C_{32}$ | Research and Development, $C_{321}$ | Research and Development, $C_{3211}$ |
| | | Technology and Engineering, $C_{33}$ | Technology and Engineering, $C_{331}$ | Technology and Engineering, $C_{3311}$ |
| | | Maintenance and Storing, $C_{34}$ | Maintenance and Storing, $C_{341}$ | Maintenance and Storing,$C_{3411}$ |
| | Outbound Logistics, $C_4$ | Transportation, $C_{41}$ | Transportation, $C_{411}$ | Transportation, $C_{4111}$ |
| | | Warehousing, $C_{42}$ | Warehouse Costs, $C_{421}$ | Warehouse Costs, $C_{4211}$ |
| | | | Inventory Flow Rate, $C_{422}$ | Inventory Flow Rate, $C_{4221}$ |
| | | | Inventory Accuracy, $C_{423}$ | Inventory Accuracy,$C_{4231}$ |
| | | | Stock Capacity, $C_{424}$ | Stock Capacity, $C_{4241}$ |
| | | | Facility Utilization, $C_{425}$ | Facility Utilization,$C_{4251}$ |
| | | Packing and Shipping, $C_{43}$ | Packing and Shipping, $C_{431}$ | Packing and Shipping, $C_{4311}$ |
| | Marketing and Sales, $C_5$ | Customer Order Processing and Delivery, $C_{51}$ | Response Time, $C_{511}$ | Response Time, $C_{5111}$ |
| | | | Order Fill Rate, $C_{512}$ | Order Fill Rate, $C_{5121}$ |
| | | | Order Flexibility, $C_{513}$ | Frequency,$C_{5131}$ |
| | | | | Amount, $C_{5132}$ |
| | | | Delivery Reliability, $C_{514}$ | Timeliness, $C_{5141}$ |
| | | | | Error-Free,$C_{5142}$ |
| | | Advertising and Customer Services, $C_{52}$ | Advertising and Customer Services, $C_{521}$ | Advertising and Customer Services, $C_{5211}$ |

Table 3.12: Nine-member linguistic terms and their corresponding interval-valued fuzzy numbers

| Linguistic terms for weight assignment | Linguistic terms for ratings | Interval-Valued trapezoidal fuzzy numbers |
|---|---|---|
| Absolutely low, AL | Absolutely poor, AP | [(0.0, 0.0, 0.0, 0.0; 1.0), (0.0, 0.0, 0.0, 0.0; 1.0)] |
| Very low, VL | Very poor, VP | [(0.0075, 0.0075, 0.015, 0.0525; 0.5), (0.0, 0.0, 0.02, 0.07; 1.0)] |
| Low, L | Poor, P | [(0.0875, 0.12, 0.16, 0.1825; 0.5), (0.04, 0.10, 0.18, 0.23; 1.0)] |
| Fairly low, FL | Fairly poor, FP | [(0.2325, 0.255, 0.325, 0.3575; 0.5), (0.17, 0.22, 0.36, 0.42; 1.0)] |
| Medium, M | Medium, M | [(0.4025, 0.4525, 0.5375, 0.5676; 0.5), (0.32, 0.41, 0.58, 0.65; 1.0)] |
| Fairly High, FH | Fairly satisfactory, FS | [(0.65, 0.6725, 0.7575, 0.79; 0.5), (0.58, 0.63, 0.80, 0.86; 1.0)] |
| High, H | Satisfactory, S | [(0.7825, 0.815, 0.885, 0.9075; 0.5), (0.72, 0.78, 0.92, 0.97; 1.0)] |
| Very High, VH | Very Impressive, VI | [(0.9475, 0.985, 0.9925, 0.9925; 0.5), (0.93, 0.98, 1.0, 1.0; 1.0)] |
| Absolutely high, AH | Absolutely impressive, AI | [(1.0, 1.0, 1.0, 1.0; 1.0), (1.0, 1.0, 1.0, 1.0; 1.0)] |

Table 3.13: Appropriateness rating (in linguistic scale) of 4th level indices assigned by DMs

| 4th level indices | Appropriateness rating (in linguistic scale) of 4th level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{1111}$ | S | S | FS | FS | S |
| $C_{1211}$ | VI | S | VI | VI | VI |
| $C_{1311}$ | AI | AI | VI | VI | VI |
| $C_{1321}$ | M | FS | M | M | M |
| $C_{1322}$ | FP | M | M | M | M |
| $C_{1331}$ | S | S | FS | S | S |
| $C_{1332}$ | S | VI | VI | S | S |
| $C_{2111}$ | M | FS | S | S | M |
| $C_{2211}$ | S | FS | FS | FS | S |
| $C_{2221}$ | FS | FS | FS | FS | FS |
| $C_{2231}$ | M | FP | FP | FP | FP |
| $C_{2241}$ | M | M | M | M | M |
| $C_{2311}$ | FS | M | M | M | M |
| $C_{2411}$ | VI | S | VI | VI | VI |
| $C_{3111}$ | S | S | FS | S | S |
| $C_{3121}$ | M | M | M | FS | FS |
| $C_{3131}$ | M | M | M | FS | M |
| $C_{3141}$ | VI | S | VI | VI | VI |
| $C_{3151}$ | S | FS | FS | FS | S |
| $C_{3211}$ | FS | FS | FS | FS | FS |
| $C_{3311}$ | M | FP | FP | FP | FP |
| $C_{3411}$ | M | M | M | M | M |
| $C_{4111}$ | FS | FS | M | M | M |
| $C_{4211}$ | S | S | VI | VI | VI |
| $C_{4221}$ | M | FS | S | S | M |
| $C_{4231}$ | S | FS | FS | FS | S |
| $C_{4241}$ | FS | FS | FS | FS | FS |
| $C_{4251}$ | M | FP | FP | FP | FP |
| $C_{4311}$ | M | M | M | M | M |
| $C_{5111}$ | FS | FS | M | M | M |
| $C_{5121}$ | VI | S | VI | VI | VI |
| $C_{5131}$ | M | S | S | S | M |
| $C_{5132}$ | S | FS | S | FS | S |
| $C_{5141}$ | FS | FS | FS | FS | FS |
| $C_{5142}$ | M | FP | FP | FP | FP |
| $C_{5211}$ | M | M | FS | M | M |

Table 3.14: Priority weight (in linguistic scale) of 4th level indices assigned by DMs

| 4th level indices | Priority weight (in linguistic scale) of 4th level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{1111}$ | VH | VH | H | VH | VH |
| $C_{1211}$ | FH | FH | H | H | H |
| $C_{1311}$ | AH | VH | AH | AH | AH |
| $C_{1321}$ | M | FH | FH | FH | M |
| $C_{1322}$ | AH | H | H | H | H |
| $C_{1331}$ | VH | VH | H | VH | VH |
| $C_{1332}$ | H | FH | H | H | H |
| $C_{2111}$ | AH | VH | AH | AH | AH |
| $C_{2211}$ | M | H | FH | FH | M |
| $C_{2221}$ | AH | H | H | H | H |
| $C_{2231}$ | VH | VH | H | VH | VH |
| $C_{2241}$ | FH | FH | H | H | H |
| $C_{2311}$ | AH | VH | H | AH | AH |
| $C_{2411}$ | M | FH | FH | H | M |
| $C_{3111}$ | AH | H | H | H | H |
| $C_{3121}$ | VH | VH | H | VH | VH |
| $C_{3131}$ | FH | FH | H | H | H |
| $C_{3141}$ | AH | H | AH | AH | AH |
| $C_{3151}$ | M | FH | FH | FH | M |
| $C_{3211}$ | AH | H | H | H | H |
| $C_{3311}$ | VH | VH | H | VH | VH |
| $C_{3411}$ | FH | H | H | H | H |
| $C_{4111}$ | AH | VH | AH | AH | AH |
| $C_{4211}$ | M | FH | FH | FH | M |
| $C_{4221}$ | AH | H | H | H | H |
| $C_{4231}$ | VH | VH | H | VH | VH |
| $C_{4241}$ | FH | FH | H | H | H |
| $C_{4251}$ | AH | VH | AH | H | AH |
| $C_{4311}$ | M | H | FH | FH | M |
| $C_{5111}$ | AH | H | H | H | H |
| $C_{5121}$ | VH | VH | H | VH | VH |
| $C_{5131}$ | FH | H | H | H | H |
| $C_{5132}$ | AH | VH | AH | H | AH |
| $C_{5141}$ | M | FH | FH | FH | M |
| $C_{5142}$ | AH | H | H | H | H |
| $C_{5211}$ | VH | VH | H | VH | VH |

Table 3.15: Priority weight (in linguistic scale) of 3rd level indices assigned by DMs

| 3rd level indices | Priority weight (in linguistic scale) of 3rd level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{111}$ | VH | VH | H | VH | VH |
| $C_{121}$ | FH | FH | H | H | H |
| $C_{131}$ | AH | VH | AH | AH | AH |
| $C_{132}$ | AH | VH | H | AH | AH |
| $C_{133}$ | M | FH | FH | H | M |
| $C_{211}$ | AH | VH | AH | AH | AH |
| $C_{221}$ | M | H | FH | FH | M |
| $C_{222}$ | AH | H | H | H | H |
| $C_{223}$ | VH | VH | H | VH | VH |
| $C_{224}$ | FH | FH | H | H | H |
| $C_{231}$ | AH | VH | H | AH | AH |
| $C_{241}$ | M | FH | FH | H | M |
| $C_{311}$ | AH | H | H | H | H |
| $C_{312}$ | VH | VH | H | VH | VH |
| $C_{313}$ | FH | FH | H | H | H |
| $C_{314}$ | AH | H | AH | AH | AH |
| $C_{315}$ | M | FH | FH | FH | M |
| $C_{321}$ | AH | H | H | H | H |
| $C_{331}$ | VH | VH | H | VH | VH |
| $C_{341}$ | FH | H | H | H | H |
| $C_{411}$ | AH | VH | AH | AH | AH |
| $C_{421}$ | M | FH | FH | FH | M |
| $C_{422}$ | AH | H | H | H | H |
| $C_{423}$ | VH | VH | H | VH | VH |
| $C_{424}$ | FH | FH | H | H | H |
| $C_{425}$ | AH | VH | AH | H | AH |
| $C_{431}$ | M | H | FH | FH | M |
| $C_{511}$ | AH | H | H | H | H |
| $C_{512}$ | VH | VH | H | VH | VH |
| $C_{513}$ | AH | VH | AH | AH | AH |
| $C_{514}$ | M | FH | FH | FH | M |
| $C_{521}$ | VH | VH | H | VH | VH |

Table 3.16: Priority weight (in linguistic scale) of 2nd level indices assigned by DMs

| 2nd Level indices | Priority weight (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | VH | VH | H | VH | VH |
| $C_{12}$ | FH | FH | H | H | H |
| $C_{13}$ | FH | FH | H | H | H |
| $C_{21}$ | AH | VH | AH | AH | AH |
| $C_{22}$ | M | FH | FH | H | M |
| $C_{23}$ | AH | VH | H | AH | AH |
| $C_{24}$ | M | FH | FH | H | M |
| $C_{31}$ | FH | FH | H | H | H |
| $C_{32}$ | AH | H | H | H | H |
| $C_{33}$ | VH | VH | H | VH | VH |
| $C_{34}$ | FH | H | H | H | H |
| $C_{41}$ | AH | VH | AH | AH | AH |
| $C_{42}$ | FH | H | H | H | H |
| $C_{43}$ | M | H | FH | FH | M |
| $C_{51}$ | M | FH | FH | FH | M |
| $C_{52}$ | VH | VH | H | VH | VH |

Table 3.17: Priority weight (in linguistic scale) of 1st level indices assigned by DMs

| 1st level indices | Priority weight (in linguistic scale) of 1st level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_1$ | H | H | AH | H | H |
| $C_2$ | H | VH | VH | VH | VH |
| $C_3$ | FH | FH | H | H | H |
| $C_4$ | H | VH | H | AH | AH |
| $C_5$ | M | FH | H | H | M |

Table 3.18: Aggregated fuzzy appropriateness rating and aggregated fuzzy priority weight of 4th level indices

| 4th level indices | Aggregated fuzzy appropriateness rating, $U_{ijkl}$ | Aggregated fuzzy priority weight, $w_{ijkl}$ |
|---|---|---|
| $C_{1111}$ | [(0.730,0.758,0.834,0.861;0.5), (0.664,0.720,0.872,0.926;1)] | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] |
| $C_{1211}$ | [(0.915,0.951,0.971,0.974;0.5), (0.888,0.940,0.984,0.994;1)] | [(0.730,0.758,0.834,0.861;0.5), (0.664,0.720,0.872,0.926;1)] |
| $C_{1311}$ | [(0.969,0.991,0.996,0.996;0.7), (0.958,0.988,1.000,1.000;1)] | [(0.990,0.997,0.999,0.999;0.9), (0.986,0.996,1.000,1.000;1)] |
| $C_{1321}$ | [(0.452,0.497,0.582,0.612;0.5), (0.372,0.454,0.624,0.692;1)] | [(0.551,0.585,0.670,0.701;0.5), (0.476,0.542,0.712,0.776;1)] |
| $C_{1322}$ | [(0.369, 0.413,0.495.0.525;0.5),(0.290,0.372,0.536,0.604;1)] | [(0.826,0.852,0.908,0.926;0.6), (0.776,0.824,0.936,0.976;1)] |
| $C_{1331}$ | [(0.756,0.787,0.860,0.884;0.5), (0.692,0.750,0.896,0.948;1)] | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] |
| $C_{1332}$ | [(0.849,0.883,0.928,0.942;0.5), (0.804,0.860,0.952,0.982;1)] | [(0.756,0.787,0.860,0.884;0.5), (0.692,0.750,0.896,0.948;1)] |
| $C_{2111}$ | [(0.604,0.642,0.721,0.748;0.5), (0.532,0.602,0.760,0.820;1)] | [(0.990,0.997,0.999,0.999;0.9), (0.986,0.996,1.000,1.000;1)] |
| $C_{2211}$ | [(0.703,0.730,0.809,0.837;0.5), (0.636,0.690,0.848,0.904;1)] | [(0.578,0.613,0.695,0.725;0.5), (0.504,0.572,0.736,0.798;1)] |
| $C_{2221}$ | [(0.650,0.673,0.758,0.790;0.5), (0.580,0.630,0.800,0.860;1)] | [(0.826,0.852,0.908,0.926;0.6), (0.776,0.824,0.936,0.976;1)] |
| $C_{2231}$ | [(0.267,0.295,0.368,0.400;0.5), (0.200,0.258,0.404,0.466;1)] | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] |
| $C_{2241}$ | [(0.403,0.453,0.538,0.568;0.5), (0.320,0.410,0.580,0.650;1)] | [(0.730,0.758,0.834,0.861;0.5), (0.664,0.720,0.872,0.926;1)] |
| $C_{2311}$ | [(0.452,0.497,0.582,0.612;0.5), (0.372,0.454,0.624,0.692;1)] | [(0.946,0.960,0.976,0.980;0.8), (0.930,0.952,0.984,0.988;1)] |
| $C_{2411}$ | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] | [(0.578,0.613,0.695,0.725;0.5), (0.504,0.572,0.736,0.798;1)] |
| $C_{3111}$ | [(0.756,0.787,0.860,0.884;0.5), (0.692,0.750,0.896,0.948;1)] | [(0.826,0.852,0.908,0.926;0.6), (0.776,0.824,0.936,0.976;1)] |
| $C_{3121}$ | [(0.502,0.541,0.626,0.657;0.5), (0.424,0.498,0.668,0.904;1)] | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] |
| $C_{3131}$ | [(0.452,0.497,0.582,0.612;0.5), (0.372,0.454,0.624,0.692;1)] | [(0.730,0.758,0.834,0.861;0.5), (0.664,0.720,0.872,0.926;1)] |
| $C_{3141}$ | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] | [(0.957,0.963,0.977,0.982;0.9), (0.944,0.956,0.984,0.994;1)] |
| $C_{3151}$ | [(0.703,0.730,0.809,0.837;0.5), (0.636,0.690,0.848,0.904;1)] | [(0.551,0.585,0.670,0.701;0.5), (0.476,0.542,0.712,0.776;1)] |
| $C_{3211}$ | [(0.650,0.673,0.758,0.790;0.5), (0.580,0.630,0.800,0.860;1)] | [(0.826,0.852,0.908,0.926;0.6), (0.776,0.824,0.936,0.976;1)] |
| $C_{3311}$ | [(0.267,0.295,0.368,0.400;0.5), (0.200,0.258,0.404,0.466;1)] | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] |
| $C_{3411}$ | [(0.403,0.453,0.538,0.568;0.5), (0.320,0.410,0.580,0.650;1)] | [(0.756,0.787,0.860,0.884;0.5), (0.692,0.750,0.896,0.948;1)] |
| $C_{4111}$ | [(0.502,0.541,0.626,0.657;0.5), (0.424,0.498,0.668,0.904;1)] | [(0.990,0.997,0.999,0.999;0.9), (0.986,0.996,1.000,1.000;1)] |
| $C_{4211}$ | [(0.882,0.917,0.950,0.959;0.5), (0.846,0.882,0.968,0.988;1)] | [(0.551,0.585,0.670,0.701;0.5), (0.476,0.542,0.712,0.776;1)] |
| $C_{4221}$ | [(0.604,0.642,0.721,0.748;0.5), (0.532,0.602,0.760,0.820;1)] | [(0.826,0.852,0.908,0.926;0.6), (0.776,0.824,0.936,0.976;1)] |
| $C_{4231}$ | [(0.703,0.730,0.809,0.837;0.5), (0.636,0.690,0.848,0.904;1)] | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] |
| $C_{4241}$ | [(0.650,0.673,0.758,0.790;0.5), (0.580,0.630,0.800,0.860;1)] | [(0.730,0.758,0.834,0.861;0.5), (0.664,0.720,0.872,0.926;1)] |
| $C_{4251}$ | [(0.267,0.295,0.368,0.400;0.5), (0.200,0.258,0.404,0.466;1)] | [(0.946,0.960,0.976,0.980;0.8), (0.930,0.952,0.984,0.988;1)] |
| $C_{4311}$ | [(0.403,0.453,0.538,0.568;0.5), (0.320,0.410,0.580,0.650;1)] | [(0.578,0.613,0.695,0.725;0.5), (0.504,0.572,0.736,0.798;1)] |
| $C_{5111}$ | [(0.502,0.541,0.626,0.657;0.5), (0.424,0.498,0.668,0.904;1)] | [(0.826,0.852,0.908,0.926;0.6), (0.776,0.824,0.936,0.976;1)] |
| $C_{5121}$ | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] |
| $C_{5131}$ | [(0.631,0.670,0.746,0.772;0.5), (0.560,0.632,0.784,0.842;1)] | [(0.756,0.787,0.860,0.884;0.5), (0.692,0.750,0.896,0.948;1)] |
| $C_{5132}$ | [(0.730,0.758,0.834,0.861;0.5), (0.664,0.720,0.872,0.926;1)] | [(0.946,0.960,0.976,0.980;0.8), (0.930,0.952,0.984,0.988;1)] |
| $C_{5141}$ | [(0.650,0.673,0.758,0.790;0.5), (0.580,0.630,0.800,0.860;1)] | [(0.551,0.585,0.670,0.701;0.5), (0.476,0.542,0.712,0.776;1)] |
| $C_{5142}$ | [(0.267,0.295,0.368,0.400;0.5), (0.200,0.258,0.404,0.466;1)] | [(0.826,0.852,0.908,0.926;0.6), (0.776,0.824,0.936,0.976;1)] |
| $C_{5211}$ | [(0.452,0.497,0.582,0.612;0.5), (0.372,0.454,0.624,0.692;1)] | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] |

Table 3.19: Computed fuzzy appropriateness rating and aggregated fuzzy priority weight of 3rd level indices

| 3rd level indices | Computed fuzzy appropriateness rating, $U_{ijk}$ | Aggregated fuzzy priority weight, $w_{ijk}$ |
|---|---|---|
| $C_{111}$ | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] |
| $C_{121}$ | [(0.730,0.758,0.834,0.861;0.5), (0.664,0.720,0.872,0.926;1)] | [(0.730,0.758,0.834,0.861;0.5), (0.664,0.720,0.872,0.926;1)] |
| $C_{131}$ | [(0.990,0.997,0.999,0.999;0.9), (0.986,0.996,1.000,1.000;1)] | [(0.990,0.997,0.999,0.999;0.9), (0.986,0.996,1.000,1.000;1)] |
| $C_{132}$ | [(0.340,0.407,0.584,0.665;0.5), (0.930,0.335,0.694,0.900;1)] | [(0.946,0.960,0.976,0.980;0.8), (0.930,0.952,0.984,0.988;1)] |
| $C_{133}$ | [(0.727,0.788,0.999,1.000;0.5), (0.504,0.718,1.026,1.189;1)] | [(0.578,0.613,0.695,0.725;0.5), (0.504,0.572,0.736,0.798;1)] |
| $C_{211}$ | [(0.990,0.997,0.999,0.999;0.9), (0.986,0.996,1.000,1.000;1)] | [(0.990,0.997,0.999,0.999;0.9), (0.986,0.996,1.000,1.000;1)] |
| $C_{221}$ | [(0.578,0.613,0.695,0.725;0.5), (0.504,0.572,0.736,0.798;1)] | [(0.578,0.613,0.695,0.725;0.5), (0.504,0.572,0.736,0.798;1)] |
| $C_{222}$ | [(0.826,0.852,0.908,0.926;0.6), (0.776,0.824,0.936,0.976;1)] | [(0.826,0.852,0.908,0.926;0.6), (0.776,0.824,0.936,0.976;1)] |
| $C_{223}$ | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] |
| $C_{224}$ | [(0.730,0.758,0.834,0.861;0.5), (0.664,0.720,0.872,0.926;1)] | [(0.730,0.758,0.834,0.861;0.5), (0.664,0.720,0.872,0.926;1)] |
| $C_{231}$ | [(0.946,0.960,0.976,0.980;0.8), (0.930,0.952,0.984,0.988;1)] | [(0.946,0.960,0.976,0.980;0.8), (0.930,0.952,0.984,0.988;1)] |
| $C_{241}$ | [(0.578,0.613,0.695,0.725;0.5), (0.504,0.572,0.736,0.798;1)] | [(0.578,0.613,0.695,0.725;0.5), (0.504,0.572,0.736,0.798;1)] |
| $C_{311}$ | [(0.826,0.852,0.908,0.926;0.6), (0.776,0.824,0.936,0.976;1)] | [(0.826,0.852,0.908,0.926;0.6), (0.776,0.824,0.936,0.976;1)] |
| $C_{312}$ | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] |
| $C_{313}$ | [(0.730,0.758,0.834,0.861;0.5), (0.664,0.720,0.872,0.926;1)] | [(0.730,0.758,0.834,0.861;0.5), (0.664,0.720,0.872,0.926;1)] |
| $C_{314}$ | [(0.957,0.963,0.977,0.981;0.9), (0.944,0.956,0.984,0.994;1)] | [(0.957,0.963,0.977,0.981;0.9), (0.944,0.956,0.984,0.994;1)] |
| $C_{315}$ | [(0.550,0.589,0.670,0.701;0.5), (0.476,0.542,0.712,0.776;1)] | [(0.550,0.589,0.670,0.701;0.5), (0.476,0.542,0.712,0.776;1)] |
| $C_{321}$ | [(0.826,0.852,0.908,0.926;0.6), (0.776,0.824,0.936,0.976;1)] | [(0.826,0.852,0.908,0.926;0.6), (0.776,0.824,0.936,0.976;1)] |
| $C_{331}$ | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] |
| $C_{341}$ | [(0.756,0.787,0.860,0.884;0.5), (0.692,0.750,0.896,0.948;1)] | [(0.756,0.787,0.860,0.884;0.5), (0.692,0.750,0.896,0.948;1)] |
| $C_{411}$ | [(0.990,0.997,0.999,0.999;0.9), (0.986,0.996,1.000,1.000;1)] | [(0.990,0.997,0.999,0.999;0.9), (0.986,0.996,1.000,1.000;1)] |
| $C_{421}$ | [(0.551,0.585,0.670,0.701;0.5), (0.476,0.542,0.712,0.776;1)] | [(0.551,0.585,0.670,0.701;0.5), (0.476,0.542,0.712,0.776;1)] |
| $C_{422}$ | [(0.826,0.852,0.908,0.926;0.6), (0.776,0.824,0.936,0.976;1)] | [(0.826,0.852,0.908,0.926;0.6), (0.776,0.824,0.936,0.976;1)] |
| $C_{423}$ | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] |
| $C_{424}$ | [(0.730,0.758,0.834,0.861;0.5), (0.664,0.720,0.872,0.926;1)] | [(0.730,0.758,0.834,0.861;0.5), (0.664,0.720,0.872,0.926;1)] |
| $C_{425}$ | [(0.946,0.960,0.976,0.980;0.8), (0.930,0.952,0.984,0.988;1)] | [(0.946,0.960,0.976,0.980;0.8), (0.930,0.952,0.984,0.988;1)] |
| $C_{431}$ | [(0.578,0.613,0.695,0.725;0.5), (0.504,0.572,0.736,0.798;1)] | [(0.578,0.613,0.695,0.725;0.5), (0.504,0.572,0.736,0.798;1)] |
| $C_{511}$ | [(0.826,0.852,0.908,0.926;0.6), (0.776,0.824,0.936,0.976;1)] | [(0.826,0.852,0.908,0.926;0.6), (0.776,0.824,0.936,0.976;1)] |
| $C_{512}$ | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] |
| $C_{513}$ | [(0.626,0.684,0.833,0.896;0.5), (0.986,0.616,0.918,1.056;1)] | [(0.990,0.997,0.999,0.999;0.9), (0.986,0.996,1.000,1.000;1)] |
| $C_{514}$ | [(0.355,0.408,0.585,0.671;0.5), (0.476,0.336,0.694,0.896;1)] | [(0.551,0.585,0.670,0.701;0.5), (0.476,0.542,0.712,0.776;1)] |
| $C_{521}$ | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] |

Table 3.20: Computed fuzzy appropriateness rating and aggregated fuzzy priority weight of 2nd level indices

| 2nd Level indices | Computed fuzzy appropriateness rating, $U_{ij}$ | Aggregated fuzzy priority weight, $w_{ij}$ |
|---|---|---|
| $C_{11}$ | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] |
| $C_{12}$ | [(0.730,0.758,0.834,0.861;0.5), (0.664,0.720,0.872,0.926;1)] | [(0.730,0.758,0.834,0.861;0.5), (0.664,0.720,0.872,0.926;1)] |
| $C_{13}$ | [(0.636,0.700,0.879,0.944;0.5), (0.535,0.633,0.967,1.161;1)] | [(0.730,0.758,0.834,0.861;0.5), (0.664,0.720,0.872,0.926;1)] |
| $C_{21}$ | [(0.990,0.997,0.999,0.999;0.9), (0.986,0.996,1.000,1.000;1)] | [(0.990,0.997,0.999,0.999;0.9), (0.986,0.996,1.000,1.000;1)] |
| $C_{22}$ | [(0.697,0.757,0.928,1.000;0.5), (0.565,0.683,1.029,1213;1)] | [(0.578,0.613,0.695,0.725;0.5), (0.504,0.572,0.736,0.798;1)] |
| $C_{23}$ | [(0.946,0.960,0.976,0.980;0.8), (0.930,0.952,0.984,0.988;1)] | [(0.946,0.960,0.976,0.980;0.8), (0.930,0.952,0.984,0.988;1)] |
| $C_{24}$ | [(0.578,0.613,0.695,0.725;0.5), (0.504,0.572,0.736,0.798;1)] | [(0.578,0.613,0.695,0.725;0.5), (0.504,0.572,0.736,0.798;1)] |
| $C_{31}$ | [(0.746,0.797,0.941,1.000;0.5), (0.632,0.734,1.023,1.170;1)] | [(0.730,0.758,0.834,0.861;0.5), (0.664,0.720,0.872,0.926;1)] |
| $C_{32}$ | [(0.826,0.852,0.908,0.926;0.6), (0.776,0.824,0.936,0.976;1)] | [(0.826,0.852,0.908,0.926;0.6), (0.776,0.824,0.936,0.976;1)] |
| $C_{33}$ | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] |
| $C_{34}$ | [(0.756,0.787,0.860,0.884;0.5), (0.692,0.750,0.896,0.948;1)] | [(0.756,0.787,0.860,0.884;0.5), (0.692,0.750,0.896,0.948;1)] |
| $C_{41}$ | [(0.990,0.997,0.999,0.999;0.9), (0.986,0.996,1.000,1.000;1)] | [(0.990,0.997,0.999,0.999;0.9), (0.986,0.996,1.000,1.000;1)] |
| $C_{42}$ | [(0.741,0.802,0.941,1.002;0.5), (0.627,0.732,1.024,1.172;1)] | [(0.756,0.787,0.860,0.884;0.5), (0.692,0.750,0.896,0.948;1)] |
| $C_{43}$ | [(0.578,0.613,0.695,0.725;0.5), (0.504,0.572,0.736,0.798;1)] | [(0.578,0.613,0.695,0.725;0.5), (0.504,0.572,0.736,0.798;1)] |
| $C_{51}$ | [(0.519,0.719,0.811,0.961;0.5), (0.515,0.863,0.986,1.181;1)] | [(0.551,0.585,0.670,0.701;0.5), (0.476,0.542,0.712,0.776;1)] |
| $C_{52}$ | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] | [(0.939,0.951,0.971,0.976;0.5), (0.888,0.940,0.984,0.994;1)] |

Table 3.21: Computed fuzzy appropriateness rating and aggregated fuzzy priority weight of 1st level indices

| 1st level indices | Computed fuzzy appropriateness rating, $U_i$ | Aggregated fuzzy priority weight, $w_i$ |
|---|---|---|
| $C_1$ | [(0.696,0.761.0.961,1.044;0.5),(0.556,0.680,1.080,1.317;1)] | [(0.826,0.852,0.908,0.926;0.6),(0.776,0.824,0.936,0.976;1)] |
| $C_2$ | [(0.761,0.819,0.966,1.037;0.5),(0.662,0.756,1.119,1.224;1)] | [(0.938,0.951,0.971,0.975,0.5),(0.880,0.940,0.984,0.994)] |
| $C_3$ | [(0.734,0.798,0.893,1.061;0.5),(0.685,0.719,1.094,1.067;1)] | [(0.729,0.758,0.834,0.860;0.5),(0.664,0.720,0.872,0.926;1)] |
| $C_4$ | [(0.718,0.783,0.954,1.036,0.5),(0.739,0.708,0.106,0.990;1)] | [(0.902,0.923,0.952,0.961;0.5),(0.874,0.908,0.968,0.988;1)] |
| $C_5$ | [(0.969,0.807,0.967,1.098;0.5),(0.583,0.796,1.127,1.396;1)] | [(0.604,0.641,0.720,0.784;0.5),(0.532,0.602,0.760,0.820,1)] |

Table 3.22: Computation of FPII

| 4th level indices | $\left[(1,1,1,1;1)(1,1,1,1;1)\right] - w_{ijkl}\Big] = w'_{ijkl}$ | $FPII = w'_{ijkl} \otimes U_{ijkl}$ |
|---|---|---|
| $C_{1111}$ | [(0.024,0.029,0.049,0.615;0.5),(0.006,0.016,0.060,0.112;1)] | [(0.017,0.022,0.040,0.529;0.5),(0.004,0.011,0.052,0.103;1)] |
| $C_{1211}$ | [(0.139,0.166,0.242,0.270;0.5),(0.074,0.128,0.280,0.336;1)] | [(0.127,0.157,0.235,0.263,0.5),(0.065,0.120,0.275,0.334;1)] |
| $C_{1311}$ | [(0.001,0.001,0.003,0.010;0.9),(0.000,0.000,0.004,0.014;1)] | [(0.001,0.001,0.003,0.010,0.5),(0.000,0.000,0.004,0.014;1)] |
| $C_{1321}$ | [(0.299,0.330,0.415,0.449;0.5),(0.224,0.288,0.458,0.524;1)] | [(0.135,0.164,0.241,0.274;0.5),(0.083,0.130,0.285,0.362;1)] |
| $C_{1322}$ | [(0.074,0.092,0.148,0.174;0.6),(0.024,0.064,0.176,0.224;1)] | [(0.027,0.038,0.073,0.091,0.5),(0.007,0.023,0.094,0.135;1)] |
| $C_{1331}$ | [(0.024,0.029,0.049,0.615;0.5),(0.006,0.016,0.060,0.112;1)] | [(0.018,0.022,0.042,0.543;0.5),(0.004,0.012,0.053,0.106;1)] |
| $C_{1332}$ | [(0.116,0.140,0.213,0.244;0.5),(0.052,0.104,0.250,0.308;1)] | [(0.098,0.124,0.198,0.229;0.5),(0.041,0.089,0.238,0.302;1)] |
| $C_{2111}$ | [(0.001,0.001,0.003,0.010;0.9),(0.000,0.000,0.004,0.014;1)] | [(0.009,0.001,0.002,0.0070.5),(0.000,0.000,0.003,0.011;1)] |
| $C_{2211}$ | [(0.275,0.305,0.387,0.422;0.5),(0.202,0264,0.428,0.496;1)] | [(0.193,0.222,0.312,0.353;0.5),(0.128,0.182,0.362,0.448;1)] |
| $C_{2221}$ | [(0.074,0.092,0.148,0.174;0.6),(0.024,0.064,0.176,0.224;1)] | [(0.048,0.061,0.112,0.137;0.5),(0.013,0.040,0.140,0.192;1)] |
| $C_{2231}$ | [(0.024,0.029,0.049,0.615;0.5),(0.006,0.016,0.060,0.112;1)] | [(0.006,0.008,0.018,0.245,0.5),(0.001,0.004,0.024,0.052;1)] |
| $C_{2241}$ | [(0.139,0.166,0.242,0.270;0.5),(0.074,0.128,0.280,0.336;1)] | [(0.056,0.075,0.130,0.153,0.5),(0.023,0.052,0.162,0.218;1)] |
| $C_{2311}$ | [(0.020,0.024,0.040,0.054;0.8),(0.012,0.016,0.048,0.070;1)] | [(0.009,0.012,0.023,0.033;0.5),(0.004,0.007,0.030,0.048;1)] |
| $C_{2411}$ | [(0.275,0.305,0.387,0.422;0.5),(0.202,0264,0.428,0.496;1)] | [(0.258,0.290,0.375,0.412,0.5),(0.179,0.248,0.421,0.493;1)] |
| $C_{3111}$ | [(0.074,0.092,0.148,0.174;0.6),(0.024,0.064,0.176,0.224;1)] | [(0.055,0.072,0.127,0.153;0.5),(0.016,0.048,0.157,0.212;1)] |
| $C_{3121}$ | [(0.024,0.029,0.049,0.615;0.5),(0.006,0.016,0.060,0.112;1)] | [(0.012,0.015,0.030,0.403;0.5),(0.002,0.008,0.040,0.101;1)] |
| $C_{3131}$ | [(0.139,0.166,0.242,0.270;0.5),(0.074,0.128,0.280,0.336;1)] | [(0.063,0.082,0.140,0.165;0.5),(0.027,0.058,0.174,0.232;1)] |
| $C_{3141}$ | [(0.018,0.023,0.037,0.043;0.9),(0.006,0.016,0.044,0.056;1)] | [(0.017,0.029,0.035,0.042;0.5),(0.005,0.015,0.043,0.055;1)] |
| $C_{3151}$ | [(0.299,0.330,0.415,0.449;0.5),(0.224,0.288,0.458,0.524;1)] | [(0.210,0.241,0.335,0.375;0.5),(0.142,0.198,0.388,0.473;1)] |

| | | |
|---|---|---|
| $C_{3211}$ | [(0.275,0.305,0.387,0.422;0.5),(0.202,0264,0.428,0.496;1)] | [(0.048,0.061,0.112,0.137;0.5),(0.013,0.040,0.140,0.192;1)] |
| $C_{3311}$ | [(0.074,0.092,0.148,0.174;0.6),(0.024,0.064,0.176,0.224;1)] | [(0.006,0.008,0.018,0.245,0.5),(0.001,0.004,0.024,0.052;1)] |
| $C_{3411}$ | [(0.116,0.140,0.213,0.244;0.5),(0.052,0.104,0.250,0.308;1)] | [(0.046,0.063,0.114,0.138;0.5),(0.016,0.042,0.145,0.200;1)] |
| $C_{4111}$ | [(0.001,0.001,0.003,0.010;0.9),(0.000,0.000,0.004,0.014;1)] | [(0.008,0.008,0.001,0.006;0.5),(0.000,0.000,0.027,0.012;1)] |
| $C_{4211}$ | [(0.299,0.330,0.415,0.449;0.5),(0.224,0.288,0.458,0.524;1)] | [(0.263,0.303,0.394,0.430;0.5),(0.189,0.254,0.443,0.517;1)] |
| $C_{4221}$ | [(0.074,0.092,0.148,0.174;0.6),(0.024,0.064,0.176,0.224;1)] | [(0.044,0.059,0.106,0.130;0.5),(0.012,0.038,0.133,0.183;1)] |
| $C_{4231}$ | [(0.024,0.029,0.049,0.615;0.5),(0.006,0.016,0.060,0.112;1)] | [(0.017,0.021,0.039,0.514;0.5),(0.003,0.011,0.050,0.101;1)] |
| $C_{4241}$ | [(0.139,0.166,0.242,0.270;0.5),(0.074,0.128,0.280,0.336;1)] | [(0.090,0.111,0.183,0.213;0.5),(0.042,0.080,0.224,0.289;1)] |
| $C_{4251}$ | [(0.020,0.024,0.040,0.054;0.8),(0.012,0.016,0.048,0.070;1)] | [(0.005,0.007,0.014,0.021;0.5),(0.002,0.004,0.019,0.032;1)] |
| $C_{4311}$ | [(0.275,0.305,0.387,0.422;0.5),(0.202,0264,0.428,0.496;1)] | [(0.110,0.138,0.208,0.239;0.5),(0.064,0.108,0.248,0.322;1)] |
| $C_{5111}$ | [(0.074,0.092,0.148,0.174;0.6),(0.024,0.064,0.176,0.224;1)] | [(0.037,0.049,0.092,0.114;0.5),(0.010,0.031,0.117,0.202;1)] |
| $C_{5121}$ | [(0.024,0.029,0.049,0.615;0.5),(0.006,0.016,0.060,0.112;1)] | [(0.023,0.027,0.047,0.599;0.5),(0.005,0.015,0.059,0.113;1)] |
| $C_{5131}$ | [(0.116,0.140,0.213,0.244;0.5),(0.052,0.104,0.250,0.308;1)] | [(0.073,0.094,0.159,0.188;0.5),(0.029,0.065,0.196,0.259;1)] |
| $C_{5132}$ | [(0.020,0.024,0.040,0.054;0.8),(0.012,0.016,0.048,0.070;1)] | [(0.014,0.018,0.033,0.046;0.5),(0.008,0.011,0.049,0.068;1)] |
| $C_{5141}$ | [(0.299,0.330,0.415,0.449;0.5),(0.224,0.288,0.458,0.524;1)] | [(0.194,0.222,0.314,0.354;0.5),(0.129,0.181,0.366,0.450;1)] |
| $C_{5142}$ | [(0.074,0.092,0.148,0.174;0.6),(0.024,0.064,0.176,0.224;1)] | [(0.019,0.027,0.054,0.069;0.5),(0.004,0.016,0.071,0.104;1)] |
| $C_{5211}$ | [(0.024,0.029,0.049,0.615;0.5),(0.006,0.016,0.060,0.112;1)] | [(0.011,0.014,0.028,0.376;0.5),(0.002,0.007,0.037,0.077;1)] |

Table 3.23: Ranking order of 4th level sub-criterions based on fuzzy degree of similarity

| $C_{ijkl}$ | Degree of similarity value between ($FPIIs \approx FPII_{Ideal}$) | Ranking order for 4th level sub-criterions |
|---|---|---|
| $C_{1111}$ | 0.671 | 19 |
| $C_{1211}$ | 0.775 | 7 |
| $C_{1311}$ | 0.580 | 34 |
| $C_{1321}$ | 0.785 | 6 |
| $C_{1322}$ | 0.646 | 24 |
| $C_{1331}$ | 0.674 | 19 |
| $C_{1332}$ | 0.744 | 9 |
| $C_{2111}$ | 0.578 | 35 |
| $C_{2211}$ | 0.847 | 5 |
| $C_{2221}$ | 0.676 | 17 |
| $C_{2231}$ | 0.618 | 29 |
| $C_{2241}$ | 0.691 | 13 |
| $C_{2311}$ | 0.614 | 32 |
| $C_{2411}$ | 0.901 | 2 |
| $C_{3111}$ | 0.687 | 14 |
| $C_{3121}$ | 0.640 | 26 |
| $C_{3131}$ | 0.699 | 12 |
| $C_{3141}$ | 0.616 | 31 |
| $C_{3151}$ | 0.866 | 3 |
| $C_{3211}$ | 0.676 | 18 |
| $C_{3311}$ | 0.618 | 30 |
| $C_{3411}$ | 0.678 | 16 |
| $C_{4111}$ | 0.571 | 36 |
| $C_{4211}$ | 0.921 | 1 |
| $C_{4221}$ | 0.671 | 20 |
| $C_{4231}$ | 0.669 | 22 |
| $C_{4241}$ | 0.732 | 10 |

| Table 3.23 (Continued) | | |
|---|---|---|
| $C_{ijkl}$ | Degree of similarity value between (FPIIs ≈ $FPII_{Ideal}$) | Ranking order for 4$^{th}$ level sub-criterions |
| $C_{4251}$ | 0.606 | 33 |
| $C_{4311}$ | 0.757 | 8 |
| $C_{5111}$ | 0.651 | 23 |
| $C_{5121}$ | 0.685 | 15 |
| $C_{5131}$ | 0.713 | 11 |
| $C_{5132}$ | 0.625 | 28 |
| $C_{5141}$ | 0.848 | 4 |
| $C_{5142}$ | 0.631 | 27 |
| $C_{5211}$ | 0.643 | 25 |

# CHAPTER 4

## Supply Chain Performance Benchmarking by Fuzzy-MULTIMOORA

## 4.1 Overview

In today's competitive global market, supply chain management (SCM) has become one of the interesting topics to be discussed. An efficient supply chain provides a range of benefits, including reduced cost, increased market share and sales, and sustainable customer relationship. Overall efficiency of supply chain encounters an integration of performance of all elements in the supply chain hierarchy. As such monitoring and managing overall supply chain efficiency is indeed a challenging task (Shafiee and Shams-e-alam, 2011). Supply chain performance evaluation often encounters subjective (qualitative) evaluation information (human judgment) which is basically vague in nature. Due to the uncertainty as well as vagueness involved in supply chain performance evaluation and related decision making; it requires exploration of the multi-criteria decision making (MCDM) tools and techniques. This part of work aims at development of an efficient appraisement module in supply chain performance context by using Interval-Valued Fuzzy Numbers (IVFNs) Set theory coupled with MULTIMOORA (MOORA: Multi-Objective Optimization by Ratio Analysis) approach for linguistic reasoning under group decision making. The fuzzy MULTIMOORA for group decision making adapted in this study enables to aggregate subjective assessments of the decision-makers and thus offer an opportunity to perform more robust performance appraisement as well as selection procedures of candidate enterprises operating under similar supply chain structure. The numerical example with empirical data exhibits application feasibilities for SC performance monitoring, improvement of overall supply chain performance thus facilitating various business related decision makings by applying fuzzy based MULTIMOORA approach.

## 4.2 Introduction and Research Background

Performance evaluation is an important activity for the survival and growth of any firm. As the old adage goes: ''you can't improve what you can't measure''. Given the magnitude of the organizational changes, there is a need for performance measures to gauge progress towards organizational goals, to provide feedback on efforts for continuing improvement, and to guide the transformation through successive stages (Chan, 2006). Performance measurement is related to strategic intent, and the broad set of metrics used by managers to monitor and guide an organization within acceptable and desirable parameters (Morgan, 2004). Organizations may need to carry out performance measurement for various kinds of reasons: identifying success, identifying whether they are meeting customer requirements, helping them understand their processes, identifying where problems bottlenecks, waste, etc., exist and where improvement are necessary, ensuring decisions are based on fact, not on supposition, emotion or intuition; and showing if improvement planned, actually happened (Parker, 2000).

A supply chain refers to an integrated and sequentially interrelated value system of suppliers, manufacturers, subcontractors, distributors and retailers working together with the prime purpose of creating value to the output for the ultimate end-users (Peng et al., 2008). Market globalization, intensifying competition and an increasing emphasis on customer orientation are regularly cited as catalyzing the surge in interest in supply chain management (Gunasekaran et al., 2001; Webster, 2002). Against this backdrop, effective supply chain management is treated as key to building a sustainable competitive edge through improved inter and intra-firm relationships (Ellinger, 2000).

Supply chain management has become common practice across industries since it addresses long-term strategic alliance, supplier-buyer partnerships, cross-organizational logistics management, joint planning, control of inventory, and information sharing. Effective supply chain management will lead to a lowering of the total amount of resources required to provide the necessary level of customer service to a specific segment and improving customer service through increased product availability and reduced order cycle time. Partnerships have the potential benefit of eliminating redundant pools of inventory and duplicate service operations while reducing costs (Chan et al., 2006). Knowledge of supply chain performance can help in improving overall business capability of both firm and industry level since it can enhance understanding and cooperation among supply chain members (Shepherd and Günter, 2006). Supply chain performance measurement does not only provide feedback information to reveal progress, enhance motivation and communication and diagnose problems but also facilitates inter-understanding and integration among supply chain members, as a result, overall customer satisfaction as well as competitiveness and profitability should be increased. It is therefore of critical importance for firms to be able to assess their own supply chain performance as a starting reference.

In recent years, increasing attention has been paid by academics, consultants, and operational managers to the way in which firms are seeking to make the supply chain more competitive and streamlined as a whole, rather than achieving cost reductions or profit improvements at the expense of their supply chain partners (Romano and Vinelli, 2001; Ding and Chen, 2007). Performance measurement systems (PMSs), representing a stage of monitoring as well as a performance assessment tool in a supply chain network (Kittelson and Associates, 2003), are thus becoming the key to discovering any potential problem as well as enrichment in a supply chain. According to Beamon (1999) and Shah and Singh (2001), the development of an appropriate performance measurement tool is definitely important, as it contributes to efficient SCM.

Brewer and Speh (2000) indicated that supply chain performance measurement enables firms to succeed in their supply chain initiatives. In addition, other researchers pointed out that a supply chain Performance Measurement System (PMS) plays an important role in monitoring performance, enhancing motivation, improving communications, and in diagnosing problems (Beamon, 1996; Brewer and Speh, 2000; Holmberg, 2000; Lau et al., 2001; Morash, 2001; Bullinger et al., 2002; Tan et al., 2002; Otto and Kotzab, 2003; Gunasekaran et al., 2004).

Neely et al. (1995) described performance measurement as a process of quantifying both the efficiency and the effectiveness of actions. Performance measurement is even regarded as one of the cornerstones of business excellence (Lim and Lee, 2005). It is obvious that performance measurement in supply chains is indispensable as it drives supply chain excellence and helps the firm to achieve its business goals.

A PMS is important to SCM in that it can give a quantitative measurement of the performance of the whole supply chain. This helps entities to understand their supply chain's strengths, weaknesses, current performance, and the size and nature of the gap between strategic intent and current status. This also enables entities to make informed decisions and gain insights, so that they can take appropriate action to improve their overall performance, efficiency, and effectiveness in order to sustain their competitive advantage. A credible PMS is helpful in evaluating the efficacy of a supply chain network in achieving improvement (Beamon, 1996; Shah and Singh, 2001), as well as in managing firms as they evolve towards interoperability (Blanc et al., 2007). Various approaches to performance measurement in the supply chain have been proposed; for example, Ghalayini et al. (1997) proposed an integrated dynamic PMS linking management, the process improvement team and the factory shop floor; Fawcett and Cooper (1998) conducted a longitudinal study of logistics performance measurement; Chan and Qi (2003) and Ohdar and Ray (2004) proposed a performance measurement method for SCM using a fuzzy-based approach; Gunasekaran et al. (2004) and Melnyk et al. (2004) suggested a framework of metrics-related performance measurement; Lyons et al. (2004) demonstrated a supply chain information system to measure supply chain performance; the NEVEM Working Group (1989) and Berrah and Clivillé (2007) studied supply chain performance measurement by aggregating all the individual performance measures up to a group; and Wong and Wong (2007) measured internal supply chain performance using Data Envelopment Analysis (DEA). Sharma and Bhagwat (2007) developed an integrated balanced scorecard (BSC) analytical hierarchy process (AHP) approach for supply chain management (SCM) evaluation. It aimed to measure SCM performance from the following four perspectives: finance, customer, internal business process, and learning and growth.

McCormack et al. (2008) investigated the relationship between supply chain maturity and performance, with specific references both to the business process orientation maturity model and to the supply chain operation reference model. Empirical results indicated a strong and positive statistical relationship between supply chain maturity and performance. Varma et al. (2008) used a combination of analytical hierarchy process (AHP) and balanced scorecard (BSC) for evaluating performance of the petroleum supply chain. The importance of four perspectives with respect to petroleum supply chain performance in descending order of importance came out as: customer, financial, internal business process, innovation and learning. Within these perspectives, the following factors seemed to be most important respectively: purity of product, market share, and steady supply of raw material and use of information technology.

Chen et al. (2011) constructed an alternative network DEA model that embodied the internal structure for supply chain performance evaluation. Three different network DEA models were introduced under the concept of centralized, decentralized and mixed organization mechanisms, respectively. Olugu et al. (2011) developed a set of measures for evaluating the performance of the automobile green supply chain. Ip et al. (2011) proposed an integrated approach towards modeling and measuring supply chain performance and stability using system dynamics (SD) and the autoregressive integrated moving average (ARIMA). SD and ARIMA models were developed, respectively, for modeling and measuring supply chain performance and for further analyzing and projecting supply chain stability for long-term management. A case study from typical semiconductor equipment manufacturing company was used to illustrate and validate the proposed method. The case company, named company A in this study, was a major semiconductor equipment supplier to the world crystal industry. Its crystal products were widely used in the automotive, industrial telecommunications, and consumer electronic industries. It had five factories, which were located in Hong Kong, Shenzhen, Fujian, Qingdao, and Zibo. Data used in the case study were collected directly from company A and through interviews with the senior management, including the chief operation manager and logistics manager. Effectiveness and efficiency, with six corresponding indicators (product reliability, employee fulfillment, customer fulfillment, on-time delivery, profit growth, and working efficiency), were found to be the most significant factors in the performance of the supply chain.

Elgazzar et al. (2012) developed a performance measurement method which linked supply chain (SC) processes' performance to a company's financial strategy through demonstrating and utilizing the relationship between SC processes' performance and a company's financial performance. The Dempster Shafer/Analytical Hierarchy Processes (DS/AHP) model was employed to link SC processes' performance to the company's financial performance through determining the relative importance weights of SC performance measures with respect to the priorities of financial performance. Olugu et al. (2012) presented an expert fuzzy rule-based system for closed-loop supply chain performance assessment in the automotive industry. Vaidya and Hudnurkar (2013) focused on multi-criteria supply chain performance evaluation in a case application of Indian chemical industry. The study introduced Supply Chain Performance Number (SCPN) to be computed, suggesting the present performance status of the particular supply chain. The methodology also helped to rank various links according to its performance. The analyses lead in computation of supply chain performance number (SCPN).

However, firms have found it difficult to practice SCM due to the lack of a comprehensive PMS for the supply chain (Beamon, 1999). The main reason for poor performance of supply chains is the lack of a measurement system (Morphy, 1999). The purpose of measurement and control in the supply chain is to provide management with a set of actions that can be taken in improving performance and planning competitiveness enhancing efforts (Hoek, 1998). Organizations need to measure not only the final output but also the processes involved in reaching the final output in order to locate the problem which is causing variance between the target and actual specification of the final product.

Earlier conceptual development of performance measurements in supply chain has been focused on cost-based performance measures because the metric of cost is easily understood and routinely welcomed by management (Ellram, 2002; Ballou et al., 2000). Gradually, more researches and practitioners seem to understand the shortfalls of having just a unidimesional measure which is rather inflexible and lack integration with strategic focus. Hence, from the "cost" perspective, researchers began to put in other quantitative as well as qualitative measures in supply chain benchmarking. Beamon (1999) identified three types of measure, namely resources, output and flexibility. Extending from this foundation, a framework for measuring the strategic, tactical and operational level of performance in supply chain is developed by (Gunasekaran et al., 2001).

## 4.3 Fuzzy Preliminaries

Fuzzy sets and fuzzy logic are powerful mathematical tools employed for modeling uncertain systems. A fuzzy set is an extension of a crisp set. A crisp set only allows full membership or non-membership, while fuzzy sets allow partial membership. The theoretical fundaments of fuzzy set theory were overviewed by Chen (2000).

This section presents the concepts and properties of the generalized trapezoidal fuzzy numbers as well as the generalized interval-valued trapezoidal fuzzy numbers. In addition, the arithmetic operations and aggregation of the generalized interval-valued trapezoidal fuzzy numbers have been discussed here.

### 4.3.1 The Generalized Trapezoidal Fuzzy Numbers

A fuzzy set $\tilde{A}$ in a universe of discourse $X$ is characterized by a membership function $\mu_{\tilde{A}}(x)$ which associates with each element $x$ in $X$ a real number in the interval [0, 1]. The function value $\mu_{\tilde{A}}(x)$ is termed the grade of membership of $x$ in $\tilde{A}$. A trapezoidal fuzzy number can be defined as $\tilde{A}=(a_1,a_2,a_3,a_4;w_{\tilde{A}})$ as shown in Fig. 4.1 and the membership function $\mu_{\tilde{A}}(x):R\rightarrow[0,1]$ is defined as follows:

$$\mu_{\tilde{A}}(x)=\begin{cases}\dfrac{x-a_1}{a_2-a_1}\times w_{\tilde{A}}, & x\in(a_1,a_2)\\ w_{\tilde{A}}, & x\in(a_2,a_3)\\ \dfrac{x-a_4}{a_3-a_4}\times w_{\tilde{A}}, & x\in(a_3,a_4)\\ 0, & x\in(-\infty,\ a_1)\cup(a_4,\ \infty)\end{cases} \tag{4.1}$$

Here, $a_1\leq a_2\leq a_3\leq a_4$ and $w_{\tilde{A}}\in(0,1)$

Suppose that $\tilde{a}=(a_1,a_2,a_3,a_4;w_{\tilde{A}})$ and $\tilde{b}=(b_1,b_2,b_3,b_4;w_{\tilde{B}})$ are two trapezoidal fuzzy numbers, then the operational rules of the trapezoidal fuzzy numbers $\tilde{a}$ and $\tilde{b}$ are shown as follows:

$$\tilde{a}\oplus\tilde{b}=(a_1,a_2,a_3,a_4;w_{\tilde{A}})\oplus(b_1,b_2,b_3,b_4;w_{\tilde{B}})=$$

$$(a_1+b_1,a_2+b_2,a_3+b_3,a_4+b_4;\min(w_{\tilde{A}},w_{\tilde{B}})) \tag{4.2}$$

$$\tilde{a}-\tilde{b}=(a_1,a_2,a_3,a_4;w_{\tilde{A}})-(b_1,b_2,b_3,b_4;w_{\tilde{B}})=$$

$$\left(a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1; \min\left(w_{\tilde{A}}, w_{\tilde{B}}\right)\right) \quad (4.3)$$

$$\tilde{a} \otimes \tilde{b} = \left(a_1, a_2, a_3, a_4; w_{\tilde{A}}\right) \otimes \left(b_1, b_2, b_3, b_4; w_{\tilde{B}}\right) =$$

$$\tilde{a} \otimes \tilde{b} = \left(a_1 \times b_1,\ a_2 \times b_2,\ a_3 \times b_3,\ a_4 \times b_4; \min\left(w_{\tilde{A}}, w_{\tilde{B}}\right)\right) \quad (4.4)$$

$$\tilde{a} / \tilde{b} = \left(a_1, a_2, a_3, a_4; w_{\tilde{A}}\right) \Big/ \left(b_1, b_2, b_3, b_4; w_{\tilde{B}}\right)$$

$$= \left(a_1 / b_4, a_2 / b_3, a_3 / b_2, a_4 / b_1; \min\left(w_{\tilde{A}}, w_{\tilde{B}}\right)\right) \quad (4.5)$$

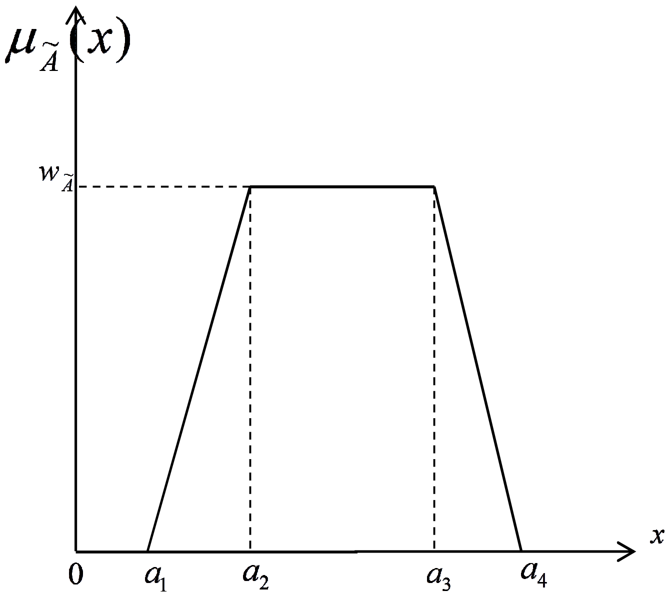



Fig. 4.1: Trapezoidal fuzzy number $\tilde{A}$

Chen and Chen (2003) introduced the center of gravity (COG) measure for generalized trapezoidal fuzzy numbers. Let there is a generalized trapezoidal fuzzy number $\tilde{A} = \left(a_1, a_2, a_3, a_4; w_{\tilde{A}}\right)$. Then it has its COG point $\left(x_{\tilde{A}}, y_{\tilde{A}}\right)$, where,

$$\begin{cases} y_{\tilde{A}} = \begin{cases} w_{\tilde{A}}\left(\dfrac{a_3 - a_2}{a_4 - a_1} + 2\right), & a_1 \neq a_4 \\ w_{\tilde{A}} \Big/ 2, & a_1 = a_4 \end{cases} \\ x_{\tilde{A}} = \dfrac{y_{\tilde{A}}(a_2 + a_3) + (a_1 + a_4) + (w_{\tilde{A}} - y_{\tilde{A}})}{2 w_{\tilde{A}}} \end{cases} \tag{4.6}$$

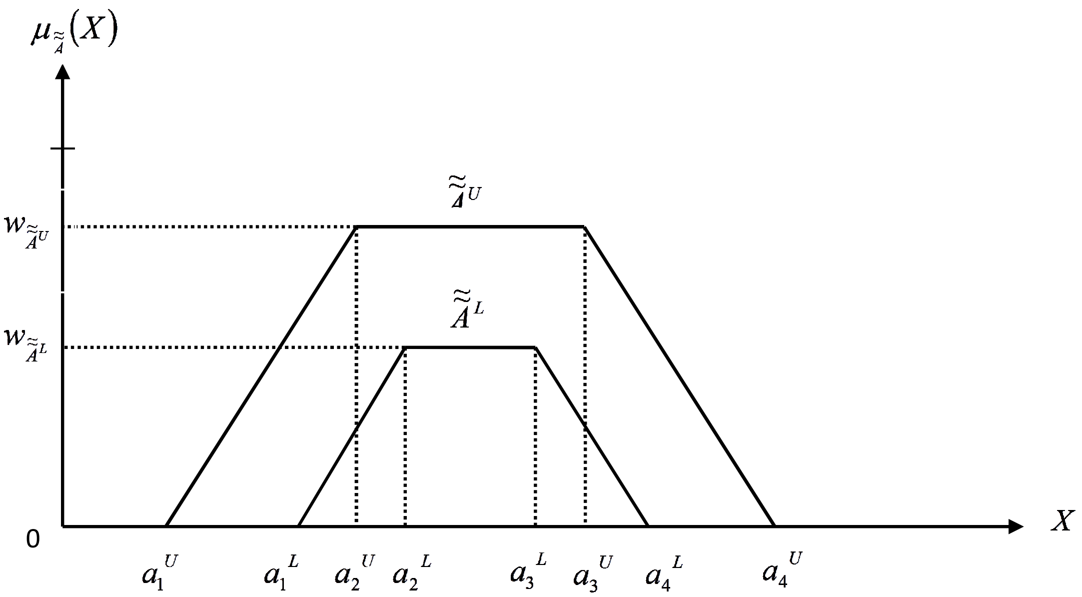



Fig. 4.2: Interval-valued trapezoidal fuzzy numbers

### 4.3.2 The Generalized Interval-Valued Trapezoidal Fuzzy Numbers

The some basic concepts of IVFNs and their arithmetic operations discussed below:

Wei and Chen (2009) defined IVFNs and presented their extended operational rules. The trapezoidal IVFN $\tilde{\tilde{A}}$ has been represented by Fig. 4.2 (Chen and Sanguansat 2011).

$$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}}^U\right)\right],$$

Here $a_1^L \le a_2^L \le a_3^L \le a_4^L$, $a_1^U \le a_2^U \le a_3^U \le a_4^U$, $\tilde{\tilde{A}}^L$ denotes the lower IVFN, $\tilde{\tilde{A}}^U$ denotes the upper IVFN, and $\tilde{\tilde{A}}^L \subset \tilde{\tilde{A}}^U$.

Assume that there are two IVFNs $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$, where;

$$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}}^U\right)\right] \text{ and}$$

$$\tilde{\tilde{B}} = \left[\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U\right] = \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}}^L\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}}^U\right)\right]$$

$$0 \le w_{\tilde{\tilde{A}}}^L \le w_{\tilde{\tilde{A}}}^U \le 1,\ \tilde{\tilde{A}}^L \subset \tilde{\tilde{A}}^U,\ 0 \le w_{\tilde{\tilde{B}}}^L \le w_{\tilde{\tilde{B}}}^U \le 1, \text{ and } \tilde{\tilde{B}}^L \subset \tilde{\tilde{B}}^U.$$

From Fig. 4.2, it can be concluded that interval-valued trapezoidal fuzzy number $\tilde{\tilde{A}}$ consists of the lower values of interval-valued trapezoidal fuzzy number $\tilde{\tilde{A}}^L$ and the upper values of interval-valued trapezoidal fuzzy number $\tilde{\tilde{A}}^U$. The operation rules of interval-valued trapezoidal fuzzy numbers as given by Wei and Chen (2009) have been reproduced below.

Suppose that,

$$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right] \text{ and}$$

$$\tilde{\tilde{B}} = \left[\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U\right] = \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$$

are the two interval-valued trapezoidal fuzzy numbers, where,

$$0 \le a_1^L \le a_2^L \le a_3^L \le a_4^L \le 1,$$
$$0 \le a_1^U \le a_2^U \le a_3^U \le a_4^U \le 1,$$
$$0 \le w_{\tilde{\tilde{A}}^L} \le w_{\tilde{\tilde{A}}^U} \le 1, \quad \tilde{\tilde{A}}^L \subset \tilde{\tilde{A}}^U$$

$$0 \le b_1^L \le b_2^L \le b_3^L \le b_4^L \le 1,$$
$$0 \le b_1^U \le b_2^U \le b_3^U \le b_4^U \le 1,$$
$$0 \le w_{\tilde{\tilde{B}}^L} \le w_{\tilde{\tilde{B}}^U} \le 1, \quad \tilde{\tilde{B}}^L \subset \tilde{\tilde{B}}^U$$

*(i)* ***The sum of two interval-valued trapezoidal fuzzy numbers*** $\tilde{\tilde{A}} \oplus \tilde{\tilde{B}}$ **:**

$$\tilde{\tilde{A}} \oplus \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right] \oplus \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$$

$$= \begin{bmatrix} \left(a_1^L + b_1^L, a_2^L + b_2^L, a_3^L + b_3^L, a_4^L + b_4^L; \min\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right)\right), \\ \left(a_1^U + b_1^U, a_2^U + b_2^U, a_3^U + b_3^U, a_4^U + b_4^U; \min\left(w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U}\right)\right) \end{bmatrix} \tag{4.7}$$

*(ii)* ***The difference of two interval-valued trapezoidal fuzzy numbers*** $\tilde{\tilde{A}} - \tilde{\tilde{B}}$ **:**

$$\tilde{\tilde{A}} - \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right] - \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$$

$$= \begin{bmatrix} \left(a_1^L - b_4^L, a_2^L - b_3^L, a_3^L - b_2^L, a_4^L - b_1^L; \min\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right)\right), \\ \left(a_1^U - b_4^U, a_2^U - b_3^U, a_3^U - b_2^U, a_4^U - b_1^U; \min\left(w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U}\right)\right) \end{bmatrix} \tag{4.8}$$

*(iii)* ***The product of two interval-valued trapezoidal fuzzy numbers*** $\tilde{\tilde{A}} \otimes \tilde{\tilde{B}}$ **:**

$$\tilde{\tilde{A}} \otimes \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right] \otimes \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$$

$$= \begin{bmatrix} \left(a_1^L \times b_1^L, a_2^L \times b_2^L, a_3^L \times b_3^L, a_4^L \times b_4^L; \min\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right)\right), \\ \left(a_1^U \times b_1^U, a_2^U \times b_2^U, a_3^U \times b_3^U, a_4^U \times b_4^U; \min\left(w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U}\right)\right) \end{bmatrix} \tag{4.9}$$

*(iv)* ***The product between an interval-valued trapezoidal fuzzy number and a constant*** $\lambda\tilde{\tilde{A}}$ **:**

$$\lambda\tilde{\tilde{A}} = \lambda \times \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right]$$

$$= \left[\left(\lambda a_1^L, \lambda a_2^L, \lambda a_3^L, \lambda a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(\lambda a_1^U, \lambda a_2^U, \lambda a_3^U, \lambda a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right], \quad \lambda > 0. \tag{4.10}$$

*(v)* ***The division between two interval-valued trapezoidal fuzzy numbers*** $\tilde{\tilde{A}}/\tilde{\tilde{B}}$

$$\tilde{\tilde{A}}/\tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right] / \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$$

$$= \begin{bmatrix} \left(\min(U^L), \min(U^L/x^L), \max(U^L/y^L), \max(U^L); \min\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right)\right), \\ \left(\min(U^U), \min(U^U/x^U), \max(U^U/y^U), \max(U^U); \min\left(w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U}\right)\right) \end{bmatrix}$$

Here,

$$U^L = \left\{\frac{a_1^L}{b_1^L}, \frac{a_2^L}{b_2^L}, \frac{a_3^L}{b_3^L}, \frac{a_4^L}{b_4^L}\right\}, U^L = \left\{\frac{a_1^U}{b_1^U}, \frac{a_2^U}{b_2^U}, \frac{a_3^U}{b_3^U}, \frac{a_4^U}{b_4^U}\right\}, \tag{4.11}$$

$$x^L = \min(U^L), x^U = \min(U^U), y^L = \max(U^L), y^U \max(U^U)$$

and the operator ''/''denotes exclusion of a certain term from sets $U^L$ and $U^U$.

*(vi)* ***Rising to the power of a constant*** $\lambda$ **,**

$$\tilde{\tilde{A}}^\lambda = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right]^\lambda$$

$$\left[\left((a_1^L)^\lambda, (a_2^L)^\lambda, (a_3^L)^\lambda, (a_4^L)^\lambda, w_{\tilde{\tilde{A}}^L}\right), \left((a_1^U)^\lambda, (a_2^U)^\lambda, (a_3^U)^\lambda, (a_4^U)^\lambda, w_{\tilde{\tilde{A}}^U}\right)\right] \tag{4.12}$$

By considering equation (6), we can define the COG point for an interval-valued trapezoidal fuzzy number $\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right]$. Firstly, equation (6) is employed to obtain the coordinates of the COG points for the lower and upper values of $\tilde{\tilde{A}}$ viz. $\left(x_{\tilde{\tilde{A}}^L}, y_{\tilde{\tilde{A}}^L}\right)$ and $\left(x_{\tilde{\tilde{A}}^U}, y_{\tilde{\tilde{A}}^U}\right)$ for $\tilde{\tilde{A}}^L$ and $\tilde{\tilde{A}}^U$, respectively. Secondly, the COG of $\left(x_{\tilde{\tilde{A}}}, y_{\tilde{\tilde{A}}}\right)$ is found as follows:

$$\begin{cases} x_{\tilde{\tilde{A}}} = \left(x_{\tilde{\tilde{A}}^L} + x_{\tilde{\tilde{A}}^U}\right)/2 \\ y_{\tilde{\tilde{A}}} = \left(y_{\tilde{\tilde{A}}^L} + y_{\tilde{\tilde{A}}^U}\right)/2 \end{cases} \tag{4.13}$$

Let there exist an interval-valued fuzzy number

$$\tilde{\tilde{B}} = \left[\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U\right] = \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$$

One can define the COG point $\left(x_{\tilde{\tilde{B}}}, y_{\tilde{\tilde{B}}}\right)$ in the spirit of equation (6). The distance $d_{\tilde{\tilde{A}}}$ and $d_{\tilde{\tilde{B}}}$ between the origin point and two generalized interval-valued trapezoidal fuzzy number $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$

$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right]$ and

$\tilde{\tilde{B}} = \left[\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U\right] = \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$ respectively, are calculated by virtue of the Euclidean distance:

$$d_{\tilde{\tilde{A}}} = \sqrt{x_{\tilde{\tilde{A}}}^2 + y_{\tilde{\tilde{A}}}^2} \tag{4.14}$$

$$d_{\tilde{\tilde{B}}} = \sqrt{x_{\tilde{\tilde{B}}}^2 + y_{\tilde{\tilde{B}}}^2} \tag{4.15}$$

Accordingly, if $d_{\tilde{\tilde{A}}} > d_{\tilde{\tilde{B}}}$, then $\tilde{\tilde{A}} \succ \tilde{\tilde{B}}$

The COG coordinates can also be employed when estimating the distance between two interval-valued trapezoidal fuzzy number say $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ (Liu, 2011)

$$d\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = \sqrt{\left\{\left(x_{\tilde{\tilde{A}}^L} - x_{\tilde{\tilde{B}}^L}\right)^2 + \left(y_{\tilde{\tilde{A}}^L} - y_{\tilde{\tilde{B}}^L}\right)^2 + \left(x_{\tilde{\tilde{A}}^U} - x_{\tilde{\tilde{B}}^U}\right)^2 + \left(y_{\tilde{\tilde{A}}^U} - y_{\tilde{\tilde{B}}^U}\right)^2\right\}/4} \tag{4.16}$$

Alternatively, one can employ the following technique (Liu and Jin, 2012):

$$d\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = \frac{1}{8}\left(\begin{array}{l} \left|w_{\tilde{\tilde{A}}^L} a_1^L - w_{\tilde{\tilde{B}}^L} b_1^L\right| + \left|w_{\tilde{\tilde{A}}^L} a_2^L - w_{\tilde{\tilde{B}}^L} b_2^L\right| + \left|w_{\tilde{\tilde{A}}^L} a_3^L - w_{\tilde{\tilde{B}}^L} b_3^L\right| \\ + \left|w_{\tilde{\tilde{A}}^L} a_4^L - w_{\tilde{\tilde{B}}^L} b_4^L\right| + \left|w_{\tilde{\tilde{A}}^U} a_1^U - w_{\tilde{\tilde{B}}^U} b_1^U\right| + \left|w_{\tilde{\tilde{A}}^U} a_2^U - w_{\tilde{\tilde{B}}^U} b_2^U\right| + \\ \left|w_{\tilde{\tilde{A}}^U} a_3^U - w_{\tilde{\tilde{B}}^U} b_3^U\right| + \left|w_{\tilde{\tilde{A}}^U} a_4^U - w_{\tilde{\tilde{B}}^U} b_4^U\right| \end{array}\right) \tag{4.17}$$

## 4.4 The Crisp MULTIMOORA Method

The Multi-Objective Optimization by Ratio Analysis (MOORA) method was introduced by Brauers and Zavadakas (2006). Brauers and Zavadakas (2010) extended the method to make it more robust as MULTIMOORA (MOORA plus the full multiplicative form).

MOORA method begins with matrix $X$ where its elements $x_{ij}$ denote $i_{th}$ alternative of $j_{th}$ objective $(i = 1,2,...,m;\ j = 1,2,...,n)$. MOORA method consists of two parts: the Ratio System and the Reference Point Approach. The MULTIMOORA method includes internal normalization and treats originally **all the objectives equally important**. In principle all stakeholders interested in the issue only could give more importance to an objective. Therefore, they could either multiply the dimensionless number representing the response on an objective with a significance coefficient or they could decide beforehand to split an objective into different sub-objectives.

***The Ratio System of MOORA***

Ratio System defines data normalization by comparing alternative of an objective to all values of the objective:

$$x_{ij}^{*} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^{2}}} \tag{4.18}$$

Here $x_{ij}^{*}$ denotes $i_{th}$ alternative of $j_{th}$ objective. Usually these numbers belong to the interval [0, 1]. These indicators are added (if desirable value of indicator is maximum) or subtracted (if desirable value is minimum), thus the summarizing index of each alternative is derived in this way:

$$y_{i}^{*} = \sum_{j=1}^{g} x_{ij}^{*} - \sum_{j=g+1}^{n} x_{ij}^{*}, \tag{4.19}$$

Here $g = 1,...,n$ denotes number of objectives to be maximized. Then every ratio is given the rank: the higher the index, the higher the rank.

In some cases, it is often observed that some attributes are more important than the others. In order to give more importance to an attribute, it could be multiplied with its corresponding weight (significance coefficient) (Brauers and Zavadskas, 2009; Chakraborty, 2011). When these attribute weights are taken into consideration, Eq. (4.19) becomes as follows:

$$y_i^* = \sum_{j=1}^{g} w_j x_{ij}^* - \sum_{j=g+1}^{n} w_j x_{ij}^*, \quad j = 1,2,...,n. \tag{4.20}$$

Here $w_j$ is the weight of $j_{th}$ attribute.

***The Reference Point of MOORA***

Reference point approach is based on the Ratio System. The Maximal Objective Reference Point (vector) is found according to ratios found by employing Eq. (4.18). The $j_{th}$ coordinate of the reference point can be described as $(r_j = \max x_{ij}^*)$ in case of maximization. Every coordinate of this vector represents maximum or minimum of certain objective (indicator). Then every element of normalized response matrix is recalculated and final rank is given according to deviation from the reference point and the Min-Max Metric of Tchebycheff:

$$\min_i \left( \max_j \left| r_j - x_{ij}^* \right| \right) \tag{4.21}$$

***The Full Multiplicative Form and MULTIMOORA***

(Brauers and Zavadskas, 2006) proposed MOORA to be updated by the Full Multiplicative Form method embodying maximization as well as minimization of purely multiplicative utility function. Overall utility of the $i_{th}$ alternative can be expressed as dimensionless number:

$$U_i^{'} = \frac{A_i}{B_i} \tag{4.22}$$

Here $A_i = \prod_{j=1}^{g} x_{ij}; i = 1,2,...,m$ denotes the product of objectives of the $i_{th}$ alternative to be maximized with $g = 1,2,...,n$ being the number of objectives to be maximized and where $B_i = \prod_{j=g+1}^{n} x_{ij}; i = 1,2,...,m$ denotes the product of objectives of the $i_{th}$ alternative to be minimized with $n - g$ being the number of objectives (indicators) to be minimized. Thus MULTIMOORA summarizes MOORA (i.e. Ratio System and Reference Point) and the Full Multiplicative Form.

## 4.5 MULTIMOORA Method Based upon IV Trapezoidal Fuzzy Numbers Set

Let $k = 1,2,...,K$ denotes the $k_{th}$ expert involved in a decision-making process. Suppose that the experts provide ratings for each $i_{th}$ alternative against each $j_{th}$ criterion with $i = 1,2,...,m$ and $j = 1,2,...,n$. The set of criteria can be split into two subsets, namely those of cost criteria, $C$, and benefit criteria, $B$. Cost criteria are to be minimized whereas; benefit criteria are to be maximized.

**Step 1:** Each of decision-makers constructs his own decision matrix:

$\left(\tilde{\tilde{A}}^k\right)_{m\times n}$ with elements $\tilde{\tilde{a}}_{ij}^k = \left[\left(a_{ijk1}^L, a_{ijk2}^L, a_{ijk3}^L, a_{ijk4}^L; w_{ijk}^L\right), \left(a_{ijk1}^U, a_{ijk2}^U, a_{ijk3}^U, a_{ijk4}^U; w_{ijk}^U\right)\right]$ being responses of alternatives on criteria.

**Step 2:** Individual decision matrices are aggregated by employing the average operator.

$$\tilde{\tilde{a}}_{ij} = \begin{bmatrix} \left(\frac{1}{K}\sum_{k=1}^{K} a_{ijk1}^L, \frac{1}{K}\sum_{k=1}^{K} a_{ijk2}^L, \frac{1}{K}\sum_{k=1}^{K} a_{ijk3}^L, \frac{1}{K}\sum_{k=1}^{K} a_{ijk4}^L; Min_k\left(w_{ijk}^L\right)\right), \\ \left(\frac{1}{K}\sum_{k=1}^{K} a_{ijk1}^U, \frac{1}{K}\sum_{k=1}^{K} a_{ijk2}^U, \frac{1}{K}\sum_{k=1}^{K} a_{ijk3}^U, \frac{1}{K}\sum_{k=1}^{K} a_{ijk4}^U; Min_k\left(w_{ijk}^U\right)\right) \end{bmatrix} \tag{4.23}$$

**Step 3:** In case some of criteria involve numeric data, the normalization has to be carried out.

$$\tilde{\tilde{x}}_{ij} = \left[\left(\frac{a_{ij1}^L}{d_j}, \frac{a_{ij2}^L}{d_j}, \frac{a_{ij3}^L}{d_j}, \frac{a_{ij4}^L}{d_j}; w_{ij}^L\right), \left(\frac{a_{ij1}^U}{d_j}, \frac{a_{ij2}^U}{d_j}, \frac{a_{ij3}^U}{d_j}, \frac{a_{ij4}^U}{d_j}; w_{ij}^U\right)\right] \tag{4.24}$$

$$= \left[\left(x_{ij1}^L, x_{ij2}^L, x_{ij3}^L, x_{ij4}^L; w_{ij}^L\right), \left(x_{ij1}^U, x_{ij2}^U, x_{ij3}^U, x_{ij4}^U; w_{ij}^U\right)\right],$$

$j = 1,2,...,n; i = 1,2,...,n.$

Here $d_j = \sqrt{\sum_{i=1}^{m}\sum_{p=1}^{4}\left(a_{ijp}^L\right)^2 + \sum_{i=1}^{m}\sum_{p=1}^{4}\left(a_{ijp}^U\right)^2}$,

$p = \{1,2,3,4\}$ for $\forall j = 1,2,...,n.$

**Step 4: The Ratio System**

The normalized values are added up for the benefit criteria and subtracted for the cost criteria:

$$RS_i = \sum_{j\in B} \approx{x}_{ij} - \sum_{j\in C} \approx{x}_{ij}$$
$$= \left[\left(RS_{i1}^L, RS_{i2}^L, RS_{i3}^L, RS_{i4}^L; w_{RS_i}^L\right), \left(RS_{i1}^U, RS_{i2}^U, RS_{i3}^U, RS_{i4}^U; w_{RS_i}^U\right)\right] \quad (4.25)$$

Here $RS_i$ denotes the overall utility of the $i_{th}$ alternative in terms of the Ratio System. The alternatives are then ranked by measuring their distances from the origin point in the spirit of Eq. (4.14). Specially, alternatives with higher distances receive higher ranks.

**Step 5: The Reference Point Approach**

For the sake of convenience one can employ the Maximal Utopian Reference Point (MURP), rather than the Maximal Objective Reference Point. In case of the generalized interval-valued trapezoidal fuzzy numbers, MURP is defined as follows:

$$\approx{r}_j = \begin{cases} (1,1,1,1;1), & \forall j \in B \\ (0,0,0,0;1), & \forall j \in C \end{cases} \quad (4.26)$$

Thereafter, Eq. (4.16) and Eq. (4.17) can be utilized to identify the maximal deviation from the MURP for each alternative:

$$\max_j d\left(\approx{r}_j, \approx{x}_{ij}\right) \quad (4.27)$$

Then the alternatives are ranked by minimizing the maximal deviances found in Eq. (4.27).

**Step 6: The Full Multiplicative Form**

The fuzzy utility of the $i_{th}$ alternative is obtained by employing Eq. (4.10) and Eq. (4.11).

$$\approx{U}_i = \frac{\approx{A}_i}{\approx{B}_i} \quad (4.28)$$

Here $\approx{A}_i = \prod_{j\in B} \approx{x}_{ij}, i = 1,2,...,m$ denotes the product of objectives of the $i_{th}$ alternative to be maximized with $B$ being the set of objectives to be maximized, and where $\approx{B}_i = \prod_{j\in C} \approx{x}_{ij}$ denotes the product of objectives of the $i_{th}$ alternative to be minimized with $C$ being the set of objectives (indicators) need to be minimized. The alternatives are ranked in descending order of $\tilde{\tilde{U}}_i$ by employing Eq. (4.14).

**Step 7:** The Dominance theory (Brauers and Zavadskas, 2011) is employed to aggregate the three ranks provided by respective parts of MULTIMOORA.

As one can note, the MULTIMOORA involves multiplication and division operations. The use of the most extreme linguistic values of zero therefore should be avoided. Otherwise, alternatives attributed with particularly low values against some criteria should be dropped from the further analysis.

## 4.6 Empirical Research

There have been attempts to systematically collate measures for evaluating the performance of supply chains. They have been grouped according to (Shepherd and Günter, 2006):

- Whether they are qualitative or quantitative (Beamon, 1999; Chan, 2003).
- What they measure: cost and non-cost (Gunasekaran, 2001; De Toni and Tonchia, 2001); quality, cost, delivery and flexibility (Schönsleben, 2004); cost, quality, resource utilization, flexibility, visibility, trust and innovativeness (Chan, 2003); resources, outputs and flexibility (Beamon, 1999); supply chain collaboration efficiency; coordination efficiency and configuration (Hieber, 2002); and, input, output and composite measures (Chan and Qi, 2003).
- Their strategic, operational or tactical focus (Gunasekaran et al., 2001).
- The process in the supply chain they relate to (Chan and Qi, 2003; Huang et al., 2004; Li et al., 2005b; Lockamy and McCormack, 2004; Stephens, 2001).

The complexity of supply chains makes collating and delineating performance metrics an onerous task (Shepherd and Günter, 2006). Table 4.1 presents the taxonomy of measures of supply chain performance, delineated according to (Gunasekaran et al., 2001), has been adapted in the present work. The definitions of various SC performance indices (as indicated in Table 4.1) have been furnished in the Appendix D (at the end of the dissertation).

Assume that there are five alternative industries the posse similar supply chain architecture. The objective is to select the best one with respect to its supply chain performance. The 2-level hierarchical model consists of various indices: measures and metrics. Strategic Performance ($C_1$), Tactical Performance ($C_2$), and Operational Performance ($C_3$) have been considered as the 1st level indices followed by 2nd level sub-indices. A MULTIMOORA approach (Kalibatas and Turskis, 2008; Chakraborty, 2011; Karande and Chakraborty, 2012; Baležentis et al., 2012; Brauers and Zavadskas, 2012; Baležentis and Zeng, 2013) combined with Interval-Valued Fuzzy Numbers Set (IVFNS) has been explored in perceptive to evaluate a supply chain performance alternative. This method has been found fruitful for solving such a group decision-making problem under uncertain environment due to vagueness, inconsistency and incompleteness associated with decision-makers' subjective evaluation information.

Empirical research has been carried out to verify application procedural steps of the aforesaid approach towards evaluation of supply chain performance alternative under a fuzzy environment. Assume that a committee of five decision-makers (expert group) such as: DM1 to DM5 has been constructed from academicians, manager of production unit, marketing unit, material purchasing unit and his/her team. Also, assume that there were five alternative supply chains such as SC1 to SC5.

In this research, priority weights against individual performance indices/sub-indices and performance extent (appropriateness ratings) corresponding to individual 2nd level sub-indices have been obtained by linguistic information, provided by the expert group; which have been further transformed into IV-trapezoidal fuzzy numbers. Here, these linguistic variables corresponding to weight assignment of various performance measures-metrics (from 1st to 2nd level of the evaluation hierarchy; Table 4.1) has been expressed in fuzzy numbers by 1-9 scale as shown in Table 4.2. Similarly, the fuzzy performance ratings of individual evaluation metrics in 2nd level have also been expressed in fuzzy numbers by 1-9 scale shown in Table 4.2. The procedural steps and its implementation results have been summarized as follows:

***Step 1: Gathering information from the expert group in relation to performance rating and importance weights of different evaluation measures/metrics using linguistic terms***

For evaluating importance weights of numerous supply chain measures/metrics (from 1st to 2nd level), as well as appropriateness rating only for 2nd level metrics; a committee of fives decision-makers (DMs), $DM_1, DM_2, DM_3, DM_4, DM_5$ has been formed to express their subjective preferences (evaluation score) in linguistic terms shown in (Table 4.2) which have been further transformed into IV-fuzzy number. The linguistic variables for assessing importance weights of various supply chain indices as given by the decision-makers (DMs) have been shown in Tables

4.3-4.4, for 2nd level and 1st level indices, respectively. The appropriateness rating (in linguistic terms) against individual 2nd level evaluation indices as assigned by the decision-makers have been furnished in Tables 4.5.1-4.5.5, for alternative SC1, SC2, SC3, SC4, and SC5, respectively.

***Step 2: Approximation of the linguistic evaluation information by IV trapezoidal fuzzy numbers***

Using the concept of generalized trapezoidal Interval-Valued fuzzy numbers in fuzzy set theory, the linguistic variables have been transformed into corresponding appropriate fuzzy numbers shown in (Table 4.2). Next, based on simple fuzzy average rule; the aggregated fuzzy priority weights have been computed and shown in Tables 4.6-4.7 for 2nd level sub-indices and 1st level indices, respectively. Similarly, aggregated performance ratings of various 2nd level sub-indices have been computed. These have been furnished in Tables 4.8.1–4.8.3 for different alternatives. Following the backward path (starting from 2nd level in the evaluation hierarchy) and exploring fuzzy weighted average rule; performance ratings of different evaluation indices at preceding level (i.e. 1st level) have been computed.

Appropriateness rating for each of the 1st level evaluation index $U_i$ (rating of $i_{th}$ index) has been computed as follows:

$$FPI = U_i = \frac{\sum U_{ij} \otimes w_{ij}}{\sum w_{ij}} \tag{4.29}$$

In this expression (Eq. 4.29) $U_{ij}$ is denoted as the aggregated fuzzy appropriateness rating (obtained through aggregating decision-makers' evaluation information) against $j_{th}$ index (at 2nd level) which is under $i_{th}$ index in the 1st level. $w_{ij}$ is the aggregated fuzzy weight against $j_{th}$ -index (at 2nd level) which is under $i_{th}$ index at 1st level.

The computation results have been shown in Tables 4.9 (for alternatives SC1 to SC5).

Thus, the problem appears to solve a feasible solution from the decision-making matrix (Eq. 4.30), involving a number of feasible alternatives corresponding to a single set (layer) of evaluation criteria. These data have been analyzed further. The computation steps have been highlighted below.

$$
|D| = \begin{array}{c} SC1 \\ SC2 \\ SC3 \\ SC4 \\ SC5 \\ \\ \end{array}
\begin{array}{c}
\begin{bmatrix}
a_{11} & a_{12} & a_{13} \\
a_{21} & a_{22} & a_{23} \\
a_{31} & a_{32} & a_{33} \\
a_{41} & a_{42} & a_{43} \\
a_{51} & a_{52} & a_{52}
\end{bmatrix} \\
\begin{array}{ccc} C_1 & C_2 & C_3 \end{array}
\end{array}
\tag{4.30}
$$

***Step 3: Normalization***

All of the indices/metric have been assumed benefit in nature and expressed in terms of generalized interval-valued trapezoidal fuzzy numbers but usually these numbers belong to the interval [0; 1] so, normalization has been carried out by employing Eq. (4.26). The normalized weighted matrix has been shown in Table 4.10. Table 4.11 represents the weighted normalized decision making matrix.

***Step 4: The Ratio System***

The Ratio System, the normalized values have been added up for the benefit criteria and (subtracted for the cost criteria) (Eq. 4.27) shown in (Table 4.12.1). In this computation priority weight of individual evaluation criterions have been considered.

***Step 5 Reference Point Approach***

We define the Reference Point (assuming all criteria are benefit in nature):

$\tilde{\tilde{r}}_i = (1,1,1,1;1)$

Thus, the ranking order of the alternatives in terms of their distances can be computed from Eqs. (4.14-4.17). A Smaller distances of measures corresponds to higher ranking position (Table 4.12.2).

***Step 6 The Full Multiplicative Form***

The Eq. (4.30) has been employed to obtain ranking order for each of alternatives according to the MOORA method with Full Multiplicative Form and the results have been shown in Table 4.12.3.

***Step 7 Final Ranking Order Utilizing Dominance Theory***

By using different computational concepts in MOORA method: *Ratio System*, *Reference Point* and *Full Multiplicative Form* to rank the supply chain performance alternatives; the Dominance

Theory (Brauers and Zavadskas, 2011) has been finally employed to summarize the three different ranking orders provided by respective parts of fuzzy integrated MULTIMOORA approach. Table 4.12.4 presents the final ranking order of feasible alternative set. According to the multi-criteria evaluation, the second alternative (SC2) should be best choice as per the judgment of decision makers, whereas the fifth alternative (SC5) is the second-best choice followed by SC1 and SC3. At the other end of spectrum, first alternative SC4 is the worst choice.

## 4.7 Managerial Implications

Supply chain management is a set of approaches utilized to efficiently integrate manufacturers, suppliers, warehouses and stores in order to produce and distribute products and services to the customers at the right quantities, right locations at the right time, and thereby, minimizing the system wide expenses whilst satisfying the service level requirements (Wong and Wong, 2007). According to (Bhagwat and Sharma, 2007) performance measurement explains the feedback on operations which are geared towards customer satisfaction and strategic decisions as well as objectives set by the organization. From a managerial point of view, this research highlights useful performance appraisement modules in favor of business organizations towards achieving competitive advantage in the marketplace. The practice of SC performance assessment is very helpful in monitoring ongoing performance status of different key elements of the SC and to compare the existing performance level to the benchmarked (desired) performance reference frame. Through performance assessment, managers can easily monitor and identify ill-performing areas within a SC and can plan accordingly for future improvement. Moreover, SC performance measurement may be facilitated by the abundant benefits of the proposed Interval-Valued Fuzzy Numbers (IVFNs) Set theory coupled with MULTIMOORA approach in deriving the performance ranking order of candidate organizations operating under similar SC hierarchy. Organizations that develop the ability to successfully create an efficient and effective SC would likely hold a substantial advantage over competitors in the market.

## 4.8 Concluding Remarks

Supply chain management has gained vital importance as one of the 21st century manufacturing paradigms for improving organizational competitiveness. The literature on SCM that provides in-depth understanding on strategies and technologies for effectively managing a supply chain is quite vast. Recently, organizational performance measurement (PM) and metrics have received remarkable concern from both the researchers as well as the management practitioners (Kamalabadi et al., 2008; Shafiee and Shams-e-alam, 2011). Performance measurement and metrics are indeed helpful in various business situations like setting of objectives, evaluating performance, and determining future courses of actions.

The goal of this study is to develop an appraisement platform in relation to supply chain performance measurement by use of FMADM (Fuzzy Multi Attribute Decision Making) method.

Multi criteria decision making (MCDM) often involves uncertainty which can be tackled by employing the fuzzy set theory. Interval-Valued Fuzzy Numbers sets offer certain additional means over generalized fuzzy numbers.

In the process of supply chain performance measurement, many of our data are qualitative. Since the qualitative data are ambiguous we transform the qualitative terms into quantities terms by using the fuzzy collections. This work, therefore, explores the MULTIMOORA method with generalized interval-valued trapezoidal fuzzy numbers. The proposed method thus provides the means for multi-criteria decision making related to uncertain assessments. Industries may adopt this appraisement module as a test-kit towards monitoring of ongoing supply chain performance, towards comparing performance extent of different industries running under similar supply chain network. This may also help in benchmarking of industries with respect to their supply chain performance extent.

Table 4.1: Evaluation Index System of Supply Chain Performance [Gunasekaran et al., 2001]

| Goal | 1st Level Indices | 2nd Level sub-Indices |
|---|---|---|
| Evaluation Index of Supply Chain Performance, C | Strategic Performance, $C_1$ | Total Supply Chain Cycle Time, $C_{11}$ |
| | | Total Cash Flow Time, $C_{12}$ |
| | | Customer Query Time, $C_{13}$ |
| | | Level of Customer Perceived Value of Product, $C_{14}$ |
| | | Net Profit vs. Productivity Ratio, $C_{15}$ |
| | | Rate on Return on Investment, $C_{16}$ |
| | | Range of Product and Services, $C_{17}$ |
| | | Variations Against Budget, $C_{18}$ |
| | | Order Lead Time, $C_{19}$ |
| | | Flexibility of Service Systems to Meet Particular Customer Needs, $C_{1,10}$ |
| | | Buyer-Supplier Partnership Level, $C_{1,11}$ |
| | | Supplier Lead Time Against Industry Norm, $C_{1,12}$ |
| | | Level of Suppliers' Defect Free Deliveries, $C_{1,13}$ |
| | | Delivery Lead Time, $C_{1,14}$ |
| | | Delivery Performance, $C_{1,15}$ |
| | Tactical Performance, $C_2$ | Accuracy of Forecasting Techniques, $C_{21}$ |
| | | Product Development Cycle Time, $C_{22}$ |
| | | Order Entry Methods, $C_{23}$ |
| | | Effectiveness of Delivery Invoice Methods, $C_{24}$ |
| | | Purchase Order Cycle Time, $C_{25}$ |
| | | Planned Process Cycle Time, $C_{26}$ |
| | | Effectiveness of Master Production Schedule, $C_{27}$ |
| | | Supplier Assistance in Solving Technical Problems, $C_{28}$ |
| | | Supplier Ability to Respond to Quality Problems, $C_{29}$ |
| | | Supplier Cost Saving Initiatives, $C_{2,10}$ |
| | | Supplier's Booking in Procedures, $C_{2,11}$ |
| | | Delivery Reliability, $C_{2,12}$ |
| | | Responsiveness to Urgent Deliveries, $C_{2,13}$ |
| | | Effectiveness of Distribution Planning Schedule, $C_{2,14}$ |
| | Operational Performance, $C_3$ | Cost Per Operation Hour, $C_{31}$ |
| | | Information Carrying Cost, $C_{32}$ |
| | | Capacity Utilization, $C_{33}$ |

| | | |
|---|---|---|
| | | Incoming Stock Level, $C_{34}$ |
| | | Work-in-Progress, $C_{35}$ |
| | | Scrap Level, $C_{36}$ |
| | | Finished Goods in Transit, $C_{37}$ |
| | | Supplier Rejection Rate, $C_{38}$ |
| | | Quality of Delivery Documentation, $C_{39}$ |
| | | Efficiency of Purchase Order Cycle Time, $C_{3,10}$ |
| | | Frequency of Delivery, $C_{3,11}$ |
| | | Quality of Delivered Goods, $C_{3,12}$ |
| | | Achievement of Defect Free Deliveries, $C_{3,13}$ |

Table 4.2: The scale of attribute weights as well as performance ratings

| Scale for weight | Scale for rating | Fuzzy Numbers |
|---|---|---|
| Absolutely Low (AL) | Absolutely Poor (AP) | [(0.0, 0.0, 0.0, 0.0; 0.8), (0.0, 0.0, 0.0, 0.0; 1.0)] |
| Very Low (VL) | Very Poor (VP) | [(0.0, 0.0, 0.02, 0.07; 0.8), (0.0, 0.0, 0.02, 0.07; 1.0)] |
| Low (L) | Poor (P) | [(0.04, 0.10, 0.18, 0.23; 0.8), (0.04, 0.10, 0.18, 0.23; 1.0)] |
| Medium Low (ML) | Medium Poor (MP) | [(0.17, 0.22, 0.36, 0.42; 0.8), (0.17, 0.22, 0.36, 0.42; 1.0)] |
| Medium (M) | Medium (M) | [(0.32, 0.41, 0.58, 0.65; 0.8), (0.32, 0.41, 0.58, 0.65; 1.0)] |
| Medium High (MH) | Medium Good (MG) | [(0.58, 0.63, 0.80, 0.86; 0.8), (0.58, 0.63, 0.80, 0.86; 1.0)] |
| High (H) | Good (G) | [(0.72, 0.78, 0.92, 0.97; 0.8), (0.72, 0.78, 0.92, 0.97; 1.0)] |
| Very High (VH) | Very Good (VG) | [(0.93, 0.98, 1.00, 1.00; 0.8), (0.93, 0.98, 1.00, 1.00; 1.0)] |
| Absolutely High (AH) | Absolutely Good (AG) | [(1.00, 1.00, 1.00, 1.00; 1.0), (1.00, 1.00, 1.00, 1.00; 1.0)] |

Table 4.3: Priority Weight (in linguistic scale) of 2nd level indices assigned by DMs

| 2nd level sub-indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | H | H | VH | H | H |
| $C_{12}$ | H | H | H | H | H |
| $C_{13}$ | VH | H | H | H | H |
| $C_{14}$ | MH | H | VH | H | H |
| $C_{15}$ | MH | H | MH | H | H |
| $C_{16}$ | H | H | MH | H | H |
| $C_{17}$ | VH | MH | H | VH | H |
| $C_{18}$ | VH | H | VH | H | H |
| $C_{19}$ | H | H | VH | H | VH |
| $C_{1,10}$ | H | H | H | H | H |
| $C_{1,11}$ | VH | H | H | H | H |
| $C_{1,12}$ | MH | MH | VH | H | H |
| $C_{1,13}$ | MH | H | MH | H | H |
| $C_{1,14}$ | H | H | MH | H | H |
| $C_{1,15}$ | VH | H | H | VH | VH |
| $C_{21}$ | VH | H | H | H | H |
| $C_{22}$ | H | H | VH | H | H |
| $C_{23}$ | H | H | H | H | H |
| $C_{24}$ | VH | H | H | H | H |
| $C_{25}$ | H | H | VH | H | H |
| $C_{26}$ | H | H | MH | H | MH |
| $C_{27}$ | H | H | H | H | H |
| $C_{28}$ | VH | MH | H | H | H |
| $C_{29}$ | VH | H | H | H | H |
| $C_{2,10}$ | H | H | VH | H | H |
| $C_{2,11}$ | H | H | H | H | H |
| $C_{2,12}$ | VH | H | H | H | H |
| $C_{2,13}$ | MH | H | H | H | H |
| $C_{2,14}$ | MH | H | MH | H | H |
| $C_{31}$ | H | H | MH | H | H |
| $C_{32}$ | VH | MH | H | VH | H |

Table 4.3 (Continued)

| $2^{nd}$ level sub-indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM1 | DM1 | DM1 | DM1 |
| $C_{33}$ | VH | H | H | H | H |
| $C_{34}$ | H | H | H | H | H |
| $C_{35}$ | H | H | H | H | H |
| $C_{36}$ | VH | H | H | H | H |
| $C_{37}$ | H | H | VH | H | H |
| $C_{38}$ | MH | H | H | H | H |
| $C_{39}$ | H | H | MH | H | H |
| $C_{3,10}$ | H | MH | H | H | H |
| $C_{3,11}$ | VH | H | H | H | VH |
| $C_{3,12}$ | H | H | VH | H | H |
| $C_{3,13}$ | H | H | H | H | H |

Table 4.4: Priority Weight (in linguistic scale) of $1^{st}$ level indices assigned by DMs

| $1^{st}$ level indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_1$ | VH | H | H | H | H |
| $C_2$ | MH | MH | H | H | H |
| $C_3$ | MH | H | MH | H | H |

Table 4.5.1: Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs **(Alternative SC1)**

| 2nd level sub-indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | MG | M | M | M | MG |
| $C_{12}$ | MG | G | G | G | MG |
| $C_{13}$ | G | G | G | G | MG |
| $C_{14}$ | MP | M | M | M | M |
| $C_{15}$ | P | MP | MP | MP | MP |
| $C_{16}$ | MP | M | M | MP | MP |
| $C_{17}$ | G | MG | MG | MG | MG |
| $C_{18}$ | M | MP | MG | MP | MG |
| $C_{19}$ | MG | MG | MG | M | MG |
| $C_{1,10}$ | G | G | G | G | VG |
| $C_{1,11}$ | MG | G | G | G | MG |
| $C_{1,12}$ | P | M | M | M | M |
| $C_{1,13}$ | G | MG | MG | M | MG |
| $C_{1,14}$ | G | G | G | G | MG |
| $C_{1,15}$ | MG | G | G | G | MG |
| $C_{21}$ | P | M | M | M | M |
| $C_{22}$ | P | P | P | MP | MP |
| $C_{23}$ | MP | M | MG | MP | MP |
| $C_{24}$ | G | MG | G | MG | MG |
| $C_{25}$ | M | MP | G | MP | MG |
| $C_{26}$ | MG | M | M | M | MG |
| $C_{27}$ | MG | MG | G | M | MG |
| $C_{28}$ | G | G | G | G | VG |
| $C_{29}$ | MG | G | G | G | MG |
| $C_{2,10}$ | P | M | M | M | M |
| $C_{2,11}$ | P | P | P | MP | MP |
| $C_{2,12}$ | MP | M | G | MP | MP |
| $C_{2,13}$ | G | MG | G | MG | G |
| $C_{2,14}$ | M | MP | G | P | MG |
| $C_{31}$ | MG | M | M | M | G |
| $C_{32}$ | MG | MG | MG | M | MG |

| Table 4.5.1 (Continued) | | | | | |
|---|---|---|---|---|---|
| $2^{nd}$ level sub-indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
| | DM1 | | DM1 | | DM1 |
| $C_{33}$ | G | G | G | G | VG |
| $C_{34}$ | MG | G | G | G | MG |
| $C_{35}$ | P | M | M | M | M |
| $C_{36}$ | P | P | P | MP | MP |
| $C_{37}$ | MP | M | MG | MP | MP |
| $C_{38}$ | G | MG | G | MG | G |
| $C_{39}$ | M | MP | G | P | MG |
| $C_{3,10}$ | MG | M | M | M | G |
| $C_{3,11}$ | MG | G | MG | M | MG |
| $C_{3,12}$ | G | VG | G | G | VG |
| $C_{3,13}$ | MG | G | G | G | MG |

Table 4.5.2: Appropriateness rating (in linguistic scale) of $2^{nd}$ level indices assigned by DMs **(Alternative SC2)**

| $2^{nd}$ level sub-indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | M | M | M | M | M |
| $C_{12}$ | VP | P | P | P | P |
| $C_{13}$ | MP | M | M | M | MP |
| $C_{14}$ | M | M | M | M | M |
| $C_{15}$ | MG | MG | MG | M | MG |
| $C_{16}$ | G | MG | G | MG | MG |
| $C_{17}$ | G | G | G | G | MG |
| $C_{18}$ | MP | P | MP | P | MP |
| $C_{19}$ | M | M | M | M | M |
| $C_{1,10}$ | VG | G | G | G | G |
| $C_{1,11}$ | G | G | G | G | G |
| $C_{1,12}$ | M | MG | MG | MG | M |
| $C_{1,13}$ | G | VG | VG | G | G |

| Table 4.5.2 (Continued) | | | | | |
|---|---|---|---|---|---|
| $2^{nd}$ level sub-indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
| | DM1 | | DM1 | | DM1 |
| $C_{1,14}$ | MP | M | MG | MG | MP |
| $C_{1,15}$ | P | P | VP | MP | P |
| $C_{21}$ | M | M | M | M | P |
| $C_{22}$ | G | MG | MG | G | G |
| $C_{23}$ | MG | MG | MG | M | MP |
| $C_{24}$ | MG | G | MG | M | MG |
| $C_{25}$ | G | MG | G | MG | MG |
| $C_{26}$ | G | G | G | G | MG |
| $C_{27}$ | MP | MP | MP | P | MP |
| $C_{28}$ | M | M | M | M | M |
| $C_{29}$ | VG | G | MG | G | G |
| $C_{2,10}$ | G | G | G | G | G |
| $C_{2,11}$ | M | MG | MG | MG | M |
| $C_{2,12}$ | G | VG | VG | G | G |
| $C_{2,13}$ | MP | M | MG | G | MP |
| $C_{2,14}$ | P | P | VP | MP | P |
| $C_{31}$ | M | M | M | M | P |
| $C_{32}$ | G | G | MG | G | G |
| $C_{33}$ | MG | MG | MG | M | MP |
| $C_{34}$ | MG | MG | MG | M | G |
| $C_{35}$ | G | G | G | G | MG |
| $C_{36}$ | G | G | G | G | MG |
| $C_{37}$ | MP | P | MP | P | MP |
| $C_{38}$ | M | M | M | M | M |
| $C_{39}$ | VG | G | G | G | G |
| $C_{3,10}$ | G | G | G | G | G |
| $C_{3,11}$ | M | MG | MG | G | M |
| $C_{3,12}$ | G | VG | VG | G | G |
| $C_{3,13}$ | MP | MP | MG | MG | MP |

Table 4.5.3: Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs **(Alternative SC3)**

| 2nd level sub-indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | VG | G | VG | VG | VG |
| $C_{12}$ | G | G | G | MG | G |
| $C_{13}$ | MG | MG | MG | MG | MG |
| $C_{14}$ | M | MG | M | M | M |
| $C_{15}$ | MP | P | P | P | MP |
| $C_{16}$ | M | MG | G | G | G |
| $C_{17}$ | P | P | MP | P | MP |
| $C_{18}$ | AG | AG | G | VG | VG |
| $C_{19}$ | G | G | G | G | G |
| $C_{1,10}$ | G | G | G | G | G |
| $C_{1,11}$ | M | M | M | MG | MG |
| $C_{1,12}$ | MG | M | G | G | G |
| $C_{1,13}$ | G | G | G | G | MG |
| $C_{1,14}$ | G | G | VG | VG | G |
| $C_{1,15}$ | VG | G | VG | VG | VG |
| $C_{21}$ | G | G | G | MG | G |
| $C_{22}$ | MG | G | MG | MG | MG |
| $C_{23}$ | M | MG | M | M | M |
| $C_{24}$ | MP | P | P | P | MP |
| $C_{25}$ | M | MG | G | G | G |
| $C_{26}$ | P | P | P | P | MP |
| $C_{27}$ | AG | AG | G | VG | VG |
| $C_{28}$ | G | G | G | G | G |
| $C_{29}$ | G | G | G | G | G |
| $C_{2,10}$ | M | MG | M | MG | MG |
| $C_{2,11}$ | MG | M | G | G | G |
| $C_{2,12}$ | G | G | G | G | MG |
| $C_{2,13}$ | G | G | G | VG | G |
| $C_{2,14}$ | VG | VG | VG | VG | VG |
| $C_{31}$ | G | G | G | MG | G |
| $C_{32}$ | MG | G | MG | MG | MG |

| Table 4.5.3 (Continued) | | | | | |
|---|---|---|---|---|---|
| $2^{nd}$ level sub-indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
| | DM1 | | DM1 | | DM1 |
| $C_{33}$ | M | MG | M | M | M |
| $C_{34}$ | MP | P | MP | P | MP |
| $C_{35}$ | M | MG | G | G | G |
| $C_{36}$ | P | P | P | P | MP |
| $C_{37}$ | G | AG | G | VG | VG |
| $C_{38}$ | G | G | G | G | G |
| $C_{39}$ | G | G | G | G | G |
| $C_{3,10}$ | M | M | M | MG | MG |
| $C_{3,11}$ | G | M | G | G | G |
| $C_{3,12}$ | G | G | G | G | MG |
| $C_{3,13}$ | G | G | VG | G | G |

Table 4.5.4: Appropriateness rating (in linguistic scale) of $2^{nd}$ level indices assigned by DMs **(Alternative SC4)**

| $2^{nd}$ level sub-indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | G | G | G | VG | G |
| $C_{12}$ | MG | MG | G | VG | MG |
| $C_{13}$ | G | G | G | G | G |
| $C_{14}$ | M | G | M | G | G |
| $C_{15}$ | M | M | M | M | MG |
| $C_{16}$ | MP | MP | M | M | M |
| $C_{17}$ | MG | MG | G | G | G |
| $C_{18}$ | M | M | M | M | MG |
| $C_{19}$ | G | G | G | G | VG |
| $C_{1,10}$ | M | G | MG | MG | MG |
| $C_{1,11}$ | MP | M | MP | MP | MP |
| $C_{1,12}$ | G | VG | VG | VG | VG |
| $C_{1,13}$ | G | VG | G | VG | G |

| Table 4.5.4 (Continued) | | | | | |
|---|---|---|---|---|---|
| $2^{nd}$ level sub-indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
| | DM1 | | DM1 | | DM1 |
| $C_{1,14}$ | MG | G | G | VG | MG |
| $C_{1,15}$ | G | G | G | G | G |
| $C_{21}$ | M | G | MG | G | G |
| $C_{22}$ | M | M | M | M | MG |
| $C_{23}$ | MP | MP | MP | M | M |
| $C_{24}$ | MG | MG | G | G | G |
| $C_{25}$ | M | M | M | M | MG |
| $C_{26}$ | G | G | G | G | VG |
| $C_{27}$ | M | G | G | MG | MG |
| $C_{28}$ | MP | M | MP | MP | MP |
| $C_{29}$ | G | VG | VG | G | VG |
| $C_{2,10}$ | G | G | G | G | G |
| $C_{2,11}$ | MG | MG | MG | VG | MG |
| $C_{2,12}$ | G | G | G | G | G |
| $C_{2,13}$ | M | G | MG | G | G |
| $C_{2,14}$ | M | M | MG | M | MG |
| $C_{31}$ | MP | MP | M | M | M |
| $C_{32}$ | MG | G | G | G | G |
| $C_{33}$ | M | M | M | M | MG |
| $C_{34}$ | G | G | G | G | G |
| $C_{35}$ | M | G | MG | MG | G |
| $C_{36}$ | MP | M | MP | MP | P |
| $C_{37}$ | G | VG | VG | VG | G |
| $C_{38}$ | G | G | G | VG | G |
| $C_{39}$ | MG | MG | G | VG | G |
| $C_{3,10}$ | G | G | G | G | G |
| $C_{3,11}$ | M | G | M | G | G |
| $C_{3,12}$ | M | M | M | M | G |
| $C_{3,13}$ | MP | MP | M | M | M |

Table 4.5.5: Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs **(Alternative SC5)**

| 2nd level sub-indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | M | M | M | M | MG |
| $C_{12}$ | G | G | G | G | VG |
| $C_{13}$ | M | G | MG | MG | MG |
| $C_{14}$ | MP | M | MP | MP | MP |
| $C_{15}$ | G | VG | VG | VG | VG |
| $C_{16}$ | G | VG | G | VG | G |
| $C_{17}$ | MG | G | G | VG | MG |
| $C_{18}$ | G | G | G | G | G |
| $C_{19}$ | M | G | MG | G | G |
| $C_{1,10}$ | M | M | M | M | MG |
| $C_{1,11}$ | MP | MP | MP | M | M |
| $C_{1,12}$ | MG | MG | G | G | G |
| $C_{1,13}$ | VG | VG | VG | VG | VG |
| $C_{1,14}$ | G | G | G | MG | G |
| $C_{1,15}$ | MG | G | MG | MG | MG |
| $C_{21}$ | M | MG | M | M | M |
| $C_{22}$ | MP | P | MP | P | MP |
| $C_{23}$ | M | MG | G | G | G |
| $C_{24}$ | P | P | P | P | MP |
| $C_{25}$ | G | AG | G | VG | VG |
| $C_{26}$ | G | G | G | G | G |
| $C_{27}$ | G | G | G | G | G |
| $C_{28}$ | M | M | M | MG | MG |
| $C_{29}$ | MP | P | MP | P | MP |
| $C_{2,10}$ | M | M | M | M | M |
| $C_{2,11}$ | VG | G | G | G | G |
| $C_{2,12}$ | G | G | G | G | G |
| $C_{2,13}$ | M | MG | MG | MG | M |
| $C_{2,14}$ | G | VG | VG | G | G |
| $C_{31}$ | MP | M | MG | MG | MP |
| $C_{32}$ | P | P | VP | MP | P |

| Table 4.5.5 (Continued) | | | | | |
|---|---|---|---|---|---|
| $2^{nd}$ level sub-indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
| | DM1 | | DM1 | | DM1 |
| $C_{33}$ | M | M | M | M | P |
| $C_{34}$ | G | MG | MG | G | G |
| $C_{35}$ | MG | MG | MG | M | MP |
| $C_{36}$ | VG | VG | VG | VG | VG |
| $C_{37}$ | G | G | G | MG | G |
| $C_{38}$ | MG | G | MG | MG | MG |
| $C_{39}$ | M | MG | M | M | M |
| $C_{3,10}$ | MP | P | MP | P | MP |
| $C_{3,11}$ | M | MG | G | G | G |
| $C_{3,12}$ | P | P | P | P | MP |
| $C_{3,13}$ | G | AG | G | VG | VG |

Table 4.6: Aggregated fuzzy weight of 2nd level evaluation indices

| 2nd level sub-indices | Aggregated fuzzy priority weight, ( $w_{ij}$) |
|---|---|
| $C_{11}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{12}$ | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |
| $C_{13}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{14}$ | [(0.734,0.790,0.912,0.954;0.8), (0.734,0.790,0.912,0.954;1)] |
| $C_{15}$ | [(0.664,0.720,0.872,0.926;0.8), (0.664,0.720,0.872,0.926;1)] |
| $C_{16}$ | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] |
| $C_{17}$ | [(0.776,0.830,0.928,0.960;0.8), (0.776,0.830,0.928,0.960;1)] |
| $C_{18}$ | [(0.804,0.860,0.940,0.982;0.8), (0.804,0.860,0.940,0.982;1)] |
| $C_{19}$ | [(0.804,0.860,0.940,0.982;0.8), (0.804,0.860,0.940,0.982;1)] |
| $C_{1,10}$ | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |
| $C_{1,11}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{1,12}$ | [(0.706,0.760,0.888,0.932;0.8), (0.706,0.760,0.888,0.932;1)] |
| $C_{1,13}$ | [(0.664,0.720,0.872,0.926;0.8), (0.664,0.720,0.872,0.926;1)] |
| $C_{1,14}$ | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] |
| $C_{1,15}$ | [(0.846,0.900,0.968,0.988;0.8), (0.846,0.900,0.968,0.988;1)] |
| $C_{21}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{22}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{23}$ | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |
| $C_{24}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{25}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{26}$ | [(0.664,0.720,0.872,0.926;0.8), (0.664,0.720,0.872,0.926;1)] |
| $C_{27}$ | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |
| $C_{28}$ | [(0.734,0.790,0.912,0.954;0.8), (0.734,0.790,0.912,0.954;1)] |
| $C_{29}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{2,10}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{2,11}$ | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |
| $C_{2,12}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{2,13}$ | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] |
| $C_{2,14}$ | [(0.664,0.720,0.872,0.926;0.8), (0.664,0.720,0.872,0.926;1)] |
| $C_{31}$ | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] |
| $C_{32}$ | [(0.776,0.830,0.928,0.960;0.8), (0.776,0.830,0.928,0.960;1)] |
| $C_{33}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |

Table 4.6 (Continued)

| 2nd level sub-indices | Aggregated fuzzy priority weight, ( $w_{ij}$) |
|---|---|
| $C_{34}$ | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |
| $C_{35}$ | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |
| $C_{36}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{37}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{38}$ | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] |
| $C_{39}$ | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] |
| $C_{3,10}$ | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] |
| $C_{3,11}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{3,12}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{3,13}$ | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |

Table 4.7: Aggregated fuzzy weight of 1st level evaluation indices

| 1st level indices | Aggregated Fuzzy Weight |
|---|---|
| $C_1$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_2$ | [(0.664,0.720,0.872,0.926;0.8), (0.664,0.720,0.872,0.926;1)] |
| $C_3$ | [(0.664,0.720,0.872,0.926;0.8), (0.664,0.720,0.872,0.926;1)] |

Table 4.8.1: Aggregated fuzzy appropriateness rating of 2nd level indices (SC1 & SC2)

| 2nd level sub-indices | Aggregated fuzzy appropriateness rating, $(U_{ij})_{SC1}$ | Aggregated fuzzy appropriateness rating, $(U_{ij})_{SC2}$ |
|---|---|---|
| $C_{11}$ | [(0.424,0.498,0.668,0.738;0.8), (0.424,0.498,0.668,0.738;1)] | [(0.320,0.410,0.580,0.650;0.8), (0.320,0.410,0.580,0.650;1)] |
| $C_{12}$ | [(0.664,0.720,0.872,0.926;0.8), (0.664,0.720,0.872,0.926;1)] | [(0.032,0.080,0.148,0.198;0.8), (0.032,0.080,0.148,0.198;1)] |
| $C_{13}$ | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] | [(0.260,0.334,0.492,0.558;0.8), (0.260,0.334,0.492,0.558;1)] |
| $C_{14}$ | [(0.290,0.372,0.536,0.604;0.8), (0.290,0.372,0.536,0.604;1)] | [(0.320,0.410,0.580,0.650;0.8), (0.320,0.410,0.580,0.650;1)] |
| $C_{15}$ | [(0.144,0.196,0.324,0.382;0.8), (0.144,0.196,0.324,0.382;1)] | [(0.528,0.586,0.756,0.818;0.8), (0.528,0.586,0.756,0.818;1)] |
| $C_{16}$ | [(0.230,0.296,0.448,0.512;0.8), (0.230,0.296,0.448,0.512;1)] | [(0.636,0.690,0.848,0.904;0.8), (0.636,0.690,0.848,0.904;1)] |
| $C_{17}$ | [(0.608,0.660,0.824,0.882;0.8), (0.608,0.660,0.824,0.882;1)] | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] |
| $C_{18}$ | [(0.364,0.422,0.580,0.642;0.8), (0.364,0.422,0.580,0.642;1)] | [(0.118,0.172,0.288,0.344;0.8), (0.118,0.172,0.288,0.344;1)] |
| $C_{19}$ | [(0.528,0.586,0.756,0.818;0.8), (0.528,0.586,0.756,0.818;1)] | [(0.320,0.410,0.580,0.650;0.8), (0.320,0.410,0.580,0.650;1)] |
| $C_{1,10}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{1,11}$ | [(0.664,0.720,0.872,0.928;0.8), (0.664,0.720,0.872,0.928;1)] | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |
| $C_{1,12}$ | [(0.264,0.348,0.500,0.566;0.8), (0.264,0.348,0.500,0.566;1)] | [(0.476,0.542,0.712,0.776;0.8), (0.476,0.542,0.712,0.776;1)] |
| $C_{1,13}$ | [(0.556,0.616,0.780,0.840;0.8), (0.556,0.616,0.780,0.840;1)] | [(0.804,0.860,0.940,0.982;0.8), (0.804,0.860,0.940,0.982;1)] |
| $C_{1,14}$ | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] | [(0.364,0.422,0.580,0.642;0.8), (0.364,0.422,0.580,0.642;1)] |
| $C_{1,15}$ | [(0.664,0.720,0.872,0.928;0.8), (0.664,0.720,0.872,0.928;1)] | [(0.058,0.104,0.184,0.236;0.8), (0.058,0.104,0.184,0.236;1)] |
| $C_{21}$ | [(0.264,0.348,0.500,0.566;0.8), (0.264,0.348,0.500,0.566;1)] | [(0.264,0.348,0.500,0.566;0.8), (0.264,0.348,0.500,0.566;1)] |
| $C_{22}$ | [(0.092,0.184,0.252,0.306;0.8), (0.092,0.184,0.252,0.306;1)] | [(0.664,0.720,0.872,0.926;0.8), (0.664,0.720,0.872,0.926;1)] |
| $C_{23}$ | [(0.282,0.340,0.492,0.554;0.8), (0.282,0.340,0.492,0.554;1)] | [(0.446,0.504,0.668,0.730;0.8), (0.446,0.504,0.668,0.730;1)] |
| $C_{24}$ | [(0.636,0.690,0.848,0.904;0.8), (0.636,0.690,0.848,0.904;1)] | [(0.556,0.616,0.780,0.840;0.8), (0.556,0.616,0.780,0.840;1)] |
| $C_{25}$ | [(0.392,0.452,0.604,0.664;0.8), (0.392,0.452,0.604,0.664;1)] | [(0.636,0.690,0.848,0.904;0.8), (0.636,0.690,0.848,0.904;1)] |
| $C_{26}$ | [(0.424,0.498,0.668,0.734;0.8), (0.424,0.498,0.668,0.734;1)] | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] |
| $C_{27}$ | [(0.556,0.616,0.780,0.840;0.8), (0.556,0.616,0.780,0.840;1)] | [(0.144,0.196,0.324,0.382;0.8), (0.144,0.196,0.324,0.382;1)] |
| $C_{28}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] | [(0.320,0.410,0.580,0.650;0.8), (0.320,0.410,0.580,0.650;1)] |
| $C_{29}$ | [(0.664,0.720,0.872,0.928;0.8), (0.664,0.720,0.872,0.928;1)] | [(0.734,0.790,0.912,0.954;0.8), (0.734,0.790,0.912,0.954;1)] |
| $C_{2,10}$ | [(0.264,0.348,0.500,0.566;0.8), (0.264,0.348,0.500,0.566;1)] | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |
| $C_{2,11}$ | [(0.092,0.184,0.252,0.306;0.8), (0.092,0.184,0.252,0.306;1)] | [(0.476,0.542,0.712,0.776;0.8), (0.476,0.542,0.712,0.776;1)] |
| $C_{2,12}$ | [(0.310,0.370,0.872,0.926;0.8), (0.310,0.370,0.872,0.926;1)] | [(0.804,0.860,0.940,0.982;0.8), (0.804,0.860,0.940,0.982;1)] |
| $C_{2,13}$ | [(0.664,0.720,0.872,0.928;0.8), (0.664,0.720,0.872,0.928;1)] | [(0.392,0.452,0.604,0.664;0.8), (0.392,0.452,0.604,0.664;1)] |
| $C_{2,14}$ | [(0.366,0.428,0.568,0.626;0.8), (0.366,0.428,0.568,0.626;1)] | [(0.058,0.104,0.184,0.236;0.8), (0.058,0.104,0.184,0.236;1)] |
| $C_{31}$ | [(0.452,0.528,0.692,0.756;0.8), (0.452,0.528,0.692,0.756;1)] | [(0.264,0.348,0.500,0.566;0.8), (0.264,0.348,0.500,0.566;1)] |
| $C_{32}$ | [(0.528,0.586,0.756,0.818;0.8), (0.528,0.586,0.756,0.818;1)] | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] |
| $C_{33}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] | [(0.446,0.504,0.668,0.730;0.8), (0.446,0.504,0.668,0.730;1)] |
| $C_{34}$ | [(0.664,0.720,0.872,0.928;0.8), (0.664,0.720,0.872,0.928;1)] | [(0.556,0.616,0.780,0.840;0.8), (0.556,0.616,0.780,0.840;1)] |
| $C_{35}$ | [(0.264,0.348,0.500,0.566;0.8), (0.264,0.348,0.500,0.566;1)] | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] |
| $C_{36}$ | [(0.092,0.184,0.252,0.306;0.8), (0.092,0.184,0.252,0.306;1)] | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] |
| $C_{37}$ | [(0.310,0.370,0.516,0.576;0.8), (0.310,0.370,0.516,0.576;1)] | [(0.118,0.172,0.288,0.344;0.8), (0.118,0.172,0.288,0.344;1)] |
| $C_{38}$ | [(0.664,0.720,0.872,0.928;0.8), (0.664,0.720,0.872,0.928;1)] | [(0.320,0.410,0.580,0.650;0.8), (0.320,0.410,0.580,0.650;1)] |
| $C_{39}$ | [(0.366,0.428,0.568,0.626;0.8), (0.366,0.428,0.568,0.626;1)] | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{3,10}$ | [(0.452,0.528,0.692,0.756;0.8), (0.452,0.528,0.692,0.756;1)] | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |
| $C_{3,11}$ | [(0.556,0.616,0.780,0.840;0.8), (0.556,0.616,0.780,0.840;1)] | [(0.504,0.572,0.736,0.798;0.8), (0.504,0.572,0.736,0.798;1)] |
| $C_{3,12}$ | [(0.804,0.860,0.940,0.982;0.8), (0.804,0.860,0.940,0.982;1)] | [(0.804,0.860,0.940,0.982;0.8), (0.804,0.860,0.940,0.982;1)] |
| $C_{3,13}$ | [(0.664,0.720,0.872,0.928;0.8), (0.664,0.720,0.872,0.928;1)] | [(0.334,0.384,0.536,0.596;0.8), (0.334,0.384,0.536,0.596;1)] |

Table 4.8.2: Aggregated fuzzy appropriateness rating of 2nd level indices (SC3 & SC4)

| 2nd level sub-indices | Aggregated fuzzy appropriateness rating, $(U_{ij})_{SC3}$ | Aggregated fuzzy appropriateness rating, $(U_{ij})_{SC4}$ |
|---|---|---|
| $C_{11}$ | [(0.888,0.940,0.984,0.994;0.8), (0.888,0.940,0.984,0.994;1)] | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{12}$ | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] | [(0.678,0.730,0.864,0.910;0.8), (0.678,0.730,0.864,0.910;1)] |
| $C_{13}$ | [(0.580,0.630,0.800,0.860;0.8), (0.580,0.630,0.800,0.860;1)] | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |
| $C_{14}$ | [(0.372,0.454,0.624,0.692;0.8), (0.372,0.454,0.624,0.692;1)] | [(0.560,0.632,0.784,0.842;0.8), (0.560,0.632,0.784,0.842;1)] |
| $C_{15}$ | [(0.092,0.148,0.252,0.306;0.8), (0.092,0.148,0.252,0.306;1)] | [(0.372,0.454,0.624,0.692;0.8), (0.372,0.454,0.624,0.692;1)] |
| $C_{16}$ | [(0.612,0.520,0.828,0.884;0.8), (0.612,0.520,0.828,0.884;1)] | [(0.260,0.334,0.492,0.558;0.8), (0.260,0.334,0.492,0.558;1)] |
| $C_{17}$ | [(0.092,0.148,0.252,0.306;0.8), (0.092,0.148,0.252,0.306;1)] | [(0.664,0.720,0.872,0.928;0.8), (0.664,0.720,0.872,0.928;1)] |
| $C_{18}$ | [(0.916,0.948,0.984,0.994;0.8), (0.916,0.948,0.984,0.994;1)] | [(0.372,0.454,0.624,0.692;0.8), (0.372,0.454,0.624,0.692;1)] |
| $C_{19}$ | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{1,10}$ | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] | [(0.554,0.616,0.780,0.840;0.8), (0.554,0.616,0.780,0.840;1)] |
| $C_{1,11}$ | [(0.424,0.498,0.668,0.734;0.8), (0.424,0.498,0.668,0.734;1)] | [(0.200,0.258,0.404,0.466;0.8), (0.200,0.258,0.404,0.466;1)] |
| $C_{1,12}$ | [(0.612,0.520,0.828,0.884;0.8), (0.612,0.520,0.828,0.884;1)] | [(0.888,0.940,0.984,0.994;0.8), (0.888,0.940,0.984,0.994;1)] |
| $C_{1,13}$ | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] | [(0.804,0.860,0.940,0.982;0.8), (0.804,0.860,0.940,0.982;1)] |
| $C_{1,14}$ | [(0.804,0.860,0.940,0.982;0.8), (0.804,0.860,0.940,0.982;1)] | [(0.706,0.760,0.888,0.932;0.8), (0.706,0.760,0.888,0.932;1)] |
| $C_{1,15}$ | [(0.888,0.940,0.984,0.994;0.8), (0.888,0.940,0.984,0.994;1)] | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |
| $C_{21}$ | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] | [(0.612,0.520,0.828,0.884;0.8), (0.612,0.520,0.828,0.884;1)] |
| $C_{22}$ | [(0.608,0.660,0.824,0.882;0.8), (0.608,0.660,0.824,0.882;1)] | [(0.372,0.454,0.624,0.692;0.8), (0.372,0.454,0.624,0.692;1)] |
| $C_{23}$ | [(0.372,0.454,0.624,0.692;0.8), (0.372,0.454,0.624,0.692;1)] | [(0.230,0.296,0.448,0.512;0.8), (0.230,0.296,0.448,0.512;1)] |
| $C_{24}$ | [(0.092,0.148,0.252,0.306;0.8), (0.092,0.148,0.252,0.306;1)] | [(0.664,0.720,0.872,0.928;0.8), (0.664,0.720,0.872,0.928;1)] |
| $C_{25}$ | [(0.612,0.520,0.828,0.884;0.8), (0.612,0.520,0.828,0.884;1)] | [(0.372,0.454,0.624,0.692;0.8), (0.372,0.454,0.624,0.692;1)] |
| $C_{26}$ | [(0.066,0.124,0.216,0.268;0.8), (0.066,0.124,0.216,0.268;1)] | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{27}$ | [(0.916,0.948,0.984,0.994;0.8), (0.916,0.948,0.984,0.994;1)] | [(0.584,0.646,0.804,0.862;0.8), (0.584,0.646,0.804,0.862;1)] |
| $C_{28}$ | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] | [(0.200,0.258,0.404,0.466;0.8), (0.200,0.258,0.404,0.466;1)] |
| $C_{29}$ | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] | [(0.846,0.900,0.968,0.988;0.8), (0.846,0.900,0.968,0.988;1)] |
| $C_{2,10}$ | [(0.476,0.542,0.712,0.776;0.8), (0.476,0.542,0.712,0.776;1)] | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |
| $C_{2,11}$ | [(0.612,0.520,0.828,0.884;0.8), (0.612,0.520,0.828,0.884;1)] | [(0.650,0.700,0.840,0.888;0.8), (0.650,0.700,0.840,0.888;1)] |
| $C_{2,12}$ | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |
| $C_{2,13}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] | [(0.612,0.520,0.828,0.884;0.8), (0.612,0.520,0.828,0.884;1)] |
| $C_{2,14}$ | [(0.930,0.980,1.000,1.000;0.8), (0.930,0.980,1.000,1.000;1)] | [(0.424,0.498,0.668,0.734;0.8), (0.424,0.498,0.668,0.734;1)] |
| $C_{31}$ | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] | [(0.260,0.334,0.492,0.558;0.8), (0.260,0.334,0.492,0.558;1)] |
| $C_{32}$ | [(0.608,0.660,0.824,0.882;0.8), (0.608,0.660,0.824,0.882;1)] | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] |
| $C_{33}$ | [(0.372,0.454,0.624,0.692;0.8), (0.372,0.454,0.624,0.692;1)] | [(0.372,0.454,0.624,0.692;0.8), (0.372,0.454,0.624,0.692;1)] |
| $C_{34}$ | [(0.118,0.172,0.288,0.344;0.8), (0.118,0.172,0.288,0.344;1)] | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |
| $C_{35}$ | [(0.612,0.520,0.828,0.884;0.8), (0.612,0.520,0.828,0.884;1)] | [(0.584,0.646,0.804,0.862;0.8), (0.584,0.646,0.804,0.862;1)] |
| $C_{36}$ | [(0.066,0.124,0.216,0.268;0.8), (0.066,0.124,0.216,0.268;1)] | [(0.174,0.234,0.368,0.428;0.8), (0.174,0.234,0.368,0.428;1)] |
| $C_{37}$ | [(0.860,0.904,0.968,0.988;0.8), (0.860,0.904,0.968,0.988;1)] | [(0.846,0.900,0.968,0.988;0.8), (0.846,0.900,0.968,0.988;1)] |
| $C_{38}$ | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{39}$ | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] | [(0.706,0.760,0.888,0.932;0.8), (0.706,0.760,0.888,0.932;1)] |
| $C_{3,10}$ | [(0.424,0.498,0.668,0.734;0.8), (0.424,0.498,0.668,0.734;1)] | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |
| $C_{3,11}$ | [(0.640,0.706,0.852,0.906;0.8), (0.640,0.706,0.852,0.906;1)] | [(0.560,0.632,0.784,0.842;0.8), (0.560,0.632,0.784,0.842;1)] |
| $C_{3,12}$ | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] | [(0.400,0.484,0.648,0.714;0.8), (0.400,0.484,0.648,0.714;1)] |
| $C_{3,13}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] | [(0.260,0.334,0.492,0.558;0.8), (0.260,0.334,0.492,0.558;1)] |

Table 4.8.3: Aggregated fuzzy appropriateness rating (SC5) and aggregated fuzzy priority weight of 2nd level indices

| $2^{nd}$ level sub-indices | Aggregated fuzzy appropriateness rating, $(U_{ij})_{SC5}$ |
|---|---|
| $C_{11}$ | [(0.372,0.454,0.624,0.692;0.8), (0.372,0.454,0.624,0.692;1)] |
| $C_{12}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{13}$ | [(0.556,0.616,0.780,0.840;0.8), (0.556,0.616,0.780,0.840;1)] |
| $C_{14}$ | [(0.200,0.258,0.404,0.466;0.8), (0.200,0.258,0.404,0.466;1)] |
| $C_{15}$ | [(0.888,0.940,0.984,0.994;0.8), (0.888,0.940,0.984,0.994;1)] |
| $C_{16}$ | [(0.804,0.860,0.940,0.982;0.8), (0.804,0.860,0.940,0.982;1)] |
| $C_{17}$ | [(0.706,0.760,0.888,0.932;0.8), (0.706,0.760,0.888,0.932;1)] |
| $C_{18}$ | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |
| $C_{19}$ | [(0.612,0.520,0.828,0.884;0.8), (0.612,0.520,0.828,0.884;1)] |
| $C_{1,10}$ | [(0.372,0.454,0.624,0.692;0.8), (0.372,0.454,0.624,0.692;1)] |
| $C_{1,11}$ | [(0.230,0.296,0.448,0.512;0.8), (0.230,0.296,0.448,0.512;1)] |
| $C_{1,12}$ | [(0.664,0.720,0.872,0.928;0.8), (0.664,0.720,0.872,0.928;1)] |
| $C_{1,13}$ | [(0.930,0.980,1.000,1.000;0.8), (0.930,0.980,1.000,1.000;1)] |
| $C_{1,14}$ | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] |
| $C_{1,15}$ | [(0.608,0.660,0.824,0.882;0.8), (0.608,0.660,0.824,0.882;1)] |
| $C_{21}$ | [(0.372,0.454,0.624,0.692;0.8), (0.372,0.454,0.624,0.692;1)] |
| $C_{22}$ | [(0.118,0.172,0.288,0.344;0.8), (0.118,0.172,0.288,0.344;1)] |
| $C_{23}$ | [(0.612,0.520,0.828,0.884;0.8), (0.612,0.520,0.828,0.884;1)] |
| $C_{24}$ | [(0.066,0.124,0.216,0.268;0.8), (0.066,0.124,0.216,0.268;1)] |
| $C_{25}$ | [(0.860,0.904,0.968,0.988;0.8), (0.860,0.904,0.968,0.988;1)] |
| $C_{26}$ | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |
| $C_{27}$ | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |
| $C_{28}$ | [(0.424,0.498,0.668,0.734;0.8), (0.424,0.498,0.668,0.734;1)] |
| $C_{29}$ | [(0.118,0.172,0.288,0.344;0.8), (0.118,0.172,0.288,0.344;1)] |
| $C_{2,10}$ | [(0.320,0.410,0.580,0.650;08), (0.320,0.410,0.580,0.650;1)] |
| $C_{2,11}$ | [(0.762,0.820,0.936,0.976;0.8), (0.762,0.820,0.936,0.976;1)] |
| $C_{2,12}$ | [(0.720,0.780,0.920,0.970;0.8), (0.720,0.780,0.920,0.970;1)] |
| $C_{2,13}$ | [(0.476,0.542,0.712,0.776;0.8), (0.476,0.542,0.712,0.776;1)] |
| $C_{2,14}$ | [(0.804,0.860,0.940,0.982;0.8), (0.804,0.860,0.940,0.982;1)] |
| $C_{31}$ | [(0.364,0.422,0.580,0.642;0.8), (0.364,0.422,0.580,0.642;1)] |
| $C_{32}$ | [(0.058,0.104,0.184,0.236;0.8), (0.058,0.104,0.184,0.236;1)] |
| $C_{33}$ | [(0.264,0.348,0.500,0.566;0.8), (0.264,0.348,0.500,0.566;1)] |
| $C_{34}$ | [(0.664,0.720,0.872,0.926;0.8), (0.664,0.720,0.872,0.926;1)] |
| $C_{35}$ | [(0.446,0.504,0.668,0.730;0.8), (0.446,0.504,0.668,0.730;1)] |
| $C_{36}$ | [(0.930,0.980,1.000,1.000;0.8), (0.930,0.980,1.000,1.000;1)] |
| $C_{37}$ | [(0.692,0.750,0.896,0.948;0.8), (0.692,0.750,0.896,0.948;1)] |
| $C_{38}$ | [(0.608,0.660,0.824,0.882;0.8), (0.608,0.660,0.824,0.882;1)] |
| $C_{39}$ | [(0.372,0.454,0.624,0.692;0.8), (0.372,0.454,0.624,0.692;1)] |
| $C_{3,10}$ | [(0.118,0.172,0.288,0.344;0.8), (0.118,0.172,0.288,0.344;1)] |
| $C_{3,11}$ | [(0.612,0.520,0.828,0.884;0.8), (0.612,0.520,0.828,0.884;1)] |
| $C_{3,12}$ | [(0.066,0.124,0.216,0.268;0.8), (0.066,0.124,0.216,0.268;1)] |
| $C_{3,13}$ | [(0.860,0.904,0.968,0.988;0.8), (0.860,0.904,0.968,0.988;1)] |

Table 4.9: Computed fuzzy appropriateness rating of 1st level indices

| 1st level indices | Alternative supply chains | Computed fuzzy appropriateness rating |
|---|---|---|
| $C_1$ | $SC_1$ | [(0.387,0.558,0.988,1.008;0.8), (0.387,0.558,0.988,1.008;1)] |
| | $SC_2$ | [(0.323,0.420,0.988,1.008;0.8), (0.323,0.420,0.988,1.008;1)] |
| | $SC_3$ | [(0.472,0.565,0.989,1.081;0.8), (0.472,0.565,0.989,1.081;1)] |
| | $SC_4$ | [(0.464,0.578,0.918,1.185;0.8), (0.464,0.578,0.918,1.185;1)] |
| | $SC_5$ | [(0.464,0.568,0.920,1.096;0.8), (0.464,0.568,0.920,1.096;1)] |
| $C_2$ | $SC_1$ | [(0.312,0.476,0.718,0.890;0.8), (0.312,0.476,0.718,0.890;1)] |
| | $SC_2$ | [(0.439,0.549,0.902,0.993;0.8), (0.439,0.549,0.902,0.993;1)] |
| | $SC_3$ | [(0.455,0.539,0.901,1.083;0.8), (0.455,0.539,0.901,1.083;1)] |
| | $SC_4$ | [(0.485,0.512,0.888,1.077;0.8), (0.485,0.512,0.888,1.077;1)] |
| | $SC_5$ | [(0.379,0.471,0.811,0.990;0.8), (0.379,0.471,0.811,0.990;1)] |
| $C_3$ | $SC_1$ | [(0.357,0.489,0.826,1.012;0.8), (0.357,0.489,0.826,1.012;1)] |
| | $SC_2$ | [(0.403,0.510,0.954,1.149;0.8), (0.403,0.510,0.954,1.149;1)] |
| | $SC_3$ | [(0.424,0.522,0.786,1.065;0.8), (0.424,0.522,0.786,1.065;1)] |
| | $SC_4$ | [(0.411,0.522,0.871,1.162;0.8), (0.411,0.522,0.871,1.162;1)] |
| | $SC_5$ | [(0.598,0.440,0.759,0.925;0.8), (0.598,0.440,0.759,0.925;1)] |

Table 4.10: Normalized Decision-Making Matrix

| $1^{st}$ level indices | Alternative supply chains | Computed normalized fuzzy appropriateness rating |
|---|---|---|
| $C_1$ | $SC_1$ | [(0.077,0.111,0.197,0.201;0.800), (0.077,0.111,0.197,0.201;1)] |
| | $SC_2$ | [(0.064,0.084,0.197,0.201;0.800), (0.064,0.084,0.197,0.201;1)] |
| | $SC_3$ | [(0.094,0.113,0.197,0.215;0.800), (0.094,0.113,0.197,0.215;1)] |
| | $SC_4$ | [(0.092,0.115,0.183,0.236;0.800), (0.092,0.115,0.183,0.236;1)] |
| | $SC_5$ | [(0.092,0.113,0.183,0.218;0.800), (0.092,0.113,0.183,0.218;1)] |
| $C_2$ | $SC_1$ | [(0.069,0.105,0.159,0.197;0.800), (0.069,0.105,0.159,0.197;1)] |
| | $SC_2$ | [(0.097,0.122,0.200,0.220;0.800), (0.097,0.122,0.200,0.220;1)] |
| | $SC_3$ | [(0.101,0.119,0.199,0.240;0.800), (0.101,0.119,0.199,0.240;1)] |
| | $SC_4$ | [(0.107,0.114,0.197,0.238;0.800), (0.107,0.114,0.197,0.238;1)] |
| | $SC_5$ | [(0.084,0.104,0.180,0.219;0.800), (0.084,0.104,0.180,0.219;1)] |
| $C_3$ | $SC_1$ | [(0.077,0.105,0.177,0.217;0.800), (0.077,0.105,0.177,0.217;1)] |
| | $SC_2$ | [(0.087,0.110,0.205,0.247;0.800), (0.087,0.110,0.205,0.247;1)] |
| | $SC_3$ | [(0.091,0.112,0.169,0.229;0.800), (0.091,0.112,0.169,0.229;1)] |
| | $SC_4$ | [(0.088,0.112,0.187,0.250;0.800), (0.088,0.112,0.187,0.250;1)] |
| | $SC_5$ | [(0.128,0.094,0.163,0.199;0.800), (0.128,0.094,0.163,0.199;1)] |

Table 4.11: Normalized Weighted Decision-Making Matrix

| 1st level indices | Alternative supply chains | Computed weighted normalized fuzzy appropriateness rating |
|---|---|---|
| $C_1$ | $SC_1$ | [(0.059,0.091,0.184,0.196;0.800), (0.059,0.091,0.184,0.196;1)] |
| | $SC_2$ | [(0.049,0.069,0.184,0.196;0.800), (0.049,0.069,0.184,0.196;1)] |
| | $SC_3$ | [(0.072,0.092,0.185,0.210;0.800), (0.072,0.092,0.185,0.210;1)] |
| | $SC_4$ | [(0.070,0.094,0.171,0.231;0.800), (0.070,0.094,0.171,0.231;1)] |
| | $SC_5$ | [(0.070,0.093,0.172,0.213;0.800), (0.070,0.093,0.172,0.213;1)] |
| $C_2$ | $SC_1$ | [(0.046,0.076,0.139,0.183;0.800), (0.046,0.076,0.139,0.183;1)] |
| | $SC_2$ | [(0.065,0.087,0.174,0.204;0.800), (0.065,0.087,0.174,0.204;1)] |
| | $SC_3$ | [(0.067,0.086,0.174,0.222;0.800), (0.067,0.086,0.174,0.222;1)] |
| | $SC_4$ | [(0.071,0.082,0.171,0.221;0.800), (0.071,0.082,0.171,0.221;1)] |
| | $SC_5$ | [(0.056,0.075,0.157,0.203;0.800), (0.056,0.075,0.157,0.203;1)] |
| $C_3$ | $SC_1$ | [(0.051,0.076,0.155,0.201;0.800), (0.051,0.076,0.155,0.201;1)] |
| | $SC_2$ | [(0.057,0.079,0.179,0.228;0.800), (0.057,0.079,0.179,0.228;1)] |
| | $SC_3$ | [(0.060,0.081,0.147,0.212;0.800), (0.060,0.081,0.147,0.212;1)] |
| | $SC_4$ | [(0.059,0.081,0.163,0.231;0.800), (0.059,0.081,0.163,0.231;1)] |
| | $SC_5$ | [(0.085,0.068,0.142,0.184;0.800), (0.085,0.068,0.142,0.184;1)] |

Table 4.12.1: Ranking order based on the ratio system approach of MULTIMOORA

| | The ratio system ($RS_i$) | Distance between two interval-valued trapezoidal fuzzy number $\left(d_{\tilde{\tilde{A}}}\right)$ | Ranking order |
|---|---|---|---|
| $SC_1$ | [(0.156,0.243,0.478,0.580;0.8), (0.156,0.243,0.478,0.580;1)] | 2.325 | 3 |
| $SC_2$ | [(0.171,0.235,0.537,0.628;0.8), (0.171,0.235,0.537,0.628;1)] | 2.422 | 1 |
| $SC_3$ | [(0.171,0.235,0.537,0.628;0.8), (0.171,0.235,0.537,0.628;1)] | 2.321 | 4 |
| $SC_4$ | [(0.200,0.257,0.506,0.682;0.8), (0.200,0.257,0.506,0.682;1)] | 2.283 | 5 |
| $SC_5$ | [(0.211,0.236,0.470,0.600;0.8), (0.211,0.236,0.470,0.600;1)] | 2.358 | 2 |

Table 4.12.2: Ranking order based on the reference point approach of MULTIMOORA

| | The reference point approach. [$Max_i\{d(\beta_{ij}, \beta_j)$] | Ranking order |
|---|---|---|
| $SC_1$ | 0.456 | 5 |
| $SC_2$ | 0.450 | 3~2 |
| $SC_3$ | 0.450 | 2~3 |
| $SC_4$ | 0.447 | 1 |
| $SC_5$ | 0.452 | 4 |

Table 4.12.3: Ranking based on the full multiplicative form approach of MULTIMOORA

| | The full multiplicative form | Distance between two interval-valued trapezoidal fuzzy number $\left(d_{\tilde{\tilde{A}}}\right)$ | Ranking order |
|---|---|---|---|
| $SC_1$ | [(0.000137,0.000523,0.003951,0.007198;0.8), (0.000137,0.000523,0.003951,0.007198;1)] | 2.237 | 2 |
| $SC_2$ | [(0.000182,0.000474,0.005732,0.009118;0.8), (0.000182,0.000474,0.005732,0.009118;1)] | 2.330 | 1 |
| $SC_3$ | [(0.000290,0.000640,0.004722,0.009885;0.8), (0.000290,0.000640,0.004722,0.009885;1)] | 2.183 | 4 |
| $SC_4$ | [(0.000294,0.000623,0.004787,0.011758;0.8), (0.000294,0.000623,0.004787,0.011758;1)] | 2.127 | 5 |
| $SC_5$ | [(0.000335,0.000474,0.003848,0.007957;0.8), (0.000335,0.000474,0.003848,0.007957;1)] | 2.198 | 3 |

Table 4.12.4: Ranking based on the MULTIMOORA

| | The ratio system (Ranking Order) | The reference point (Ranking Order) | The full multiplicative form (Ranking Order) | MULTIMOORA (Final ranking order) |
|---|---|---|---|---|
| $SC_1$ | 3 | 5 | 2 | 3 |
| $SC_2$ | 1 | 3 | 1 | 1 |
| $SC_3$ | 4 | 2 | 4 | 4 |
| $SC_4$ | 5 | 1 | 5 | 5 |
| $SC_5$ | 2 | 4 | 3 | 2 |

# CHAPTER 5

## Supply Chain Performance Benchmarking by Fuzzy Grey Relation Method

## 5.1 Overview

Present work aims to develop an efficient decision support system (DSS) to facilitate supply chain performance appraisement, benchmarking and related decision-making. Supply chain performance extent can be attributed as a function of multiple criteria/attributes. Most of the criterions/attributes being intangible in nature; supply chain performance appraisement relies on the subjective judgment of the decision-makers. Moreover, quantitative appraisement of supply chain performance appears to be very difficult due to involvement of ill-defined (vague) performance measures as well as metrics. In order to overcome this, this study explores the concept of fuzzy logic in order to tackle incomplete and inconsistent subjective judgment of the decision-makers' whilst evaluating supply chain overall performance. In this work, a performance appraisement index system has been articulated to gather evaluation information data (weights and ratings) in relation to supply chain performance measures and metrics. Combining the concepts of fuzzy set theory, entropy, ideal, and grey relation analysis, a fuzzy grey relation method for supply chain performance benchmarking problem has been presented. First, triangular fuzzy numbers and linguistic evaluation information characterized by triangular fuzzy numbers have been used to evaluate the importance weights of all criteria and the superiority of all alternatives versus various criteria above the alternative level. Then, the concept of entropy has been utilized to solve the adjusted integration weight of all objective criteria above the alternative level. Moreover, using the concepts of ideal, the grey ration grades of various alternatives versus ideal solution have been ranked to determine the best alternative. Finally, an empirical example of selecting most appropriate industry/enterprise or organization (corresponding supply chain) has been used to demonstrate the ease of applicability of the aforesaid approach. The study results showed that this method appears to be an effective means for tackling Multi-Criteria Decision Making (MCDM) problems in uncertain environments. Empirical data have been analyzed and results obtained thereof, have been reported to exhibit application potential of the said fuzzy grey relation based decision-support systems in appropriate situation.

## 5.2 Introduction and Research Background

With the quest of globalization, changing daily prices, increasing labor cost, involvement of sophisticated customers, a record number of companies are looking to adopt industrial supply chain tool, so that they can become more flexible, adaptive, responsive and innovative in the global marketplace. The pressure of quality, cost and delivery are the main hurdles for any company to remain competitive in today's scenario. Industrial supply chain is looked on as a tool for gaining competitive advantage. These systems provide competitive advantage at every level of the operation, if used in a proper way. Extensive literature available on supply chain reveals various facets of industrial supply chain covered by various researchers across the globe. Industrial supply chain tools can be defined according to application as well as usage. It is an automated production system of people, machines and tools for the planning and control of the production process, including procurement of raw materials, parts, components and the shipment as well as service of finished products. The benefits of industrial supply chain tools have been realized and classified into tangible and intangible components. The tangible benefits are reduced inventory, more return on equity, less cost per unit; whereas, intangible benefits are flexibility, competitive advantage, enhanced quality and improved delivery. Before going for the adoption of industrial supply chain, it should be properly understood and evaluated by the managers, so there should be a proper evaluation and selection method to help managers in selecting the suitable system. The decision is becoming increasingly complex as it involves many quantitative and qualitative attributes.

The weights of evaluation criteria are greatly influenced the final selection of any MCDM problem. The weights of criteria reflected the DM's subjective preference and it is traditionally obtained by using a preference elicitation technique, e.g. the analytic hierarchy process (AHP) approach, which was proposed by Saaty (1980). However, the weights of objective criteria above the alternatives level not only can express the explanation ability and reliability of the decision-making problem but also can represent actual conditions of decision-making and improve the quality of decision-making. Grey theory was proposed by (Deng 1982, 1989) based upon the concept that information is sometimes incomplete and/or unknown. The grey relation model is based on developmental trends, it can work well when the sample size is small and the sample distribution is unknown (Liu et al. 1999; Feng and Wang 2000). This is basically a data analysis technique that can be applied to solve MCDM problems (Liu et al. 1999). Grey relation analysis is an effective means for tackling decision analysis with incomplete information/small sample size/unknown distribution type. In order to release the limitation of decision conditions and make the decision making more relevant and effective, a fuzziness and grey based multiple criteria decision-making (FMCDM) approach has been proposed for this part of research in the context of SC performance appraisement.

In this of fuzzy multi-criteria model, Grey Relational Analysis (GRA) is suggested as a tool for implementing a multiple criteria performance scheme, which is used to identify solutions from a finite set of alternatives (Kuo, Yang, & Huang, 2008; Lin, Lee, & Chang, 2009; Tseng, 2010). Developed by Deng (1989), GRA is an impact evaluation model that can measure the degree of similarity or difference between two sequences based on the relation. The basic principle is as follows: if a comparability sequence translated from an alternative has the highest grey relational grade between the reference sequence and itself, then the alternative will be treated as the best choice. Motivated by this, present work attempts to develop a grey based SC performance appraisement/benchmarking module in fuzzy environment.

Industrial organizations are moving toward more integrated supply chains (SCs) to remain competitive. To be effectively designed and managed, these SCs need to be measured and evaluated in terms of performance in a consistent way. For this reason, it is important to acquire a common and unified understanding of the SC associated performance, process and structure concepts (Böhm et al., 2007). A supply chain embodies all such activities that influence timing, cost, quality and delivery of a product. Increased competitiveness has forced the supply chains to create new standards for improving processes. Since a benchmark is a standard that is aspired by observing a best practice, it is of immense importance in SCM. Also, supply chains are rooted with the 'extended' concept meaning that it includes suppliers, distributors and various processes involving them. Thus a single performance measure does not suffice for the entire chain. Therefore, Benchmarking and Supply chain performance measures are of prime importance in supply chain management context (Wong and Wong, 2008; Khare et al., 2012).

A supply chain consists of different levels, namely supplier, manufacturer, distributor, and consumer, and it is a network of companies which influence each other and affect one another's performance. Hence, an important issue in SCM is the development of integrated performance measurement systems (PMS). PMS serve different functions in supply chain and operations management. These are formal devices to control, formulate and communicate the company's strategy, and, as such, they primarily serve higher-level managers. But PMS can also support operational managers, to motivate and enable them to improve operations. A performance measurement framework assists in the process of performance measures building, by clarifying measurement boundaries, specifying performance measurement dimensions or views and may also provide initial intuitions into relationships among the dimensions (Rouse and Putterill, 2003; Chan, 2003).

Effective supply chain performance measurement has been identified as a key issue towards efficient supply chain management (Olugu and Wong, 2009). In the manufacturing environment, performance measurement is based on different quantitative and qualitative factors. Some of these factors may have a larger effect on the performance measure than others. Units of measure of the quantitative factors are different such as time, money, percentage, ratio, and counts. It is indeed required to develop SC performance appraisement module as an effective decision tool for the performance measurement and benchmarking in manufacturing environment (Adel El-Baz, 2011).

In this context, present work aims to explore the extent of research in supply chain performance measurement using fuzzy based grey relation approach (Liao et al., 2013). Here, most of the performance metrics being subjective in nature, a decision-making group has been recommended to collect subjective evaluation information using linguistic scale. Linguistic information has been correlated with fuzzy logic to provide a strong mathematic base to support the aforesaid evaluation and related decision-modeling.

## 5.3 Fuzzy Set Theory

Fuzzy sets and fuzzy logic are powerful mathematical tools employed for modeling uncertain systems. A fuzzy set is an extension of a crisp set. A crisp set only allows full membership or non-membership, while fuzzy sets allow partial membership. The theoretical fundaments of fuzzy set theory have been overviewed by Chen (2000). This section presents the concepts and properties of the triangular fuzzy numbers. In addition, the arithmetic operations and aggregation of the triangular fuzzy numbers have also been discussed:

### 5.3.1 Triangular Fuzzy Numbers

In a universe of discourse $X$, a fuzzy subset $A$ of $X$ is defined by a membership function $f_A(x)$, which maps each element $x$ in $X$ to a real number in the interval (0, 1). The function $f_A(x)$ value represents the grade of membership of $x$ in $A$.

A fuzzy number $A$ (Dubois and Prade 1978) in real lineis a triangular fuzzy number if its membership function $f_A : R \rightarrow (0, 1)$ is

$$f_A(x) = \begin{cases} (x-c)/(a-c), & c \le x \le a \\ (x-b)/(a-b), & a \le x \le b \\ 0 & otherwise \end{cases} \quad (5.1)$$

With $-\infty < c \le a \le b < \infty$.The triangular fuzzy number can be denoted by $(c,a,b)$.

The parameter $a$ gives the maximal grade off $f_A(x)$, i.e. $f_A(a) = 1$; it is the most probable value of the evaluation data. In addition, '$c$'and '$b$' are the lower and upper bounds of the available area for the evaluation data. They are used to reflect the fuzziness of the evaluation data. The narrower the interval $(c,b)$, the lower the fuzziness of the evaluation data and the triangular fuzzy numbers are easy to use and easy to interpret. For example, 'approximately equal to 500' can be represented by (495,500,506); and it can be represented more blurred by (490,500,513). In addition, the non-fuzzy number, an exact number, 'a' can be represented by $(a,a,a)$. For example, '500' can be represented by (500,500,500).

Let $A_1 = (c_1, a_1, b_1)$ and $A_2 = (c_2, a_2, b_2)$ be fuzzy numbers. According to the extension principle (Zadeh 1965), the algebraic operations of any two fuzzy numbers $A_1$ and $A_2$ can be expressed as

• Fuzzy addition, ⊕:

$$A_1 \oplus A_2 = (c_1 + c_2, a_1 + a_2, b_1 + b_2), \quad (5.2)$$

• Fuzzy subtraction, (-):

$$A_1 - A_2 = (c_1 - b_2, a_1 + a_2, b_1 + c_2), \quad (5.3)$$

• Fuzzy multiplication, ⊗:

$$k \otimes A_2 = (kc_2, ka_2, kb_2), \quad k \in R, \quad k \ge 0, \quad (5.4)$$

$$A_1 \otimes A_2 \cong (c_1c_2, a_1a_2, b_1b_2), \quad c_1 \ge 0, \quad c_2 \ge 0, \quad (5.5)$$

• Fuzzy division, $(/ \; or \div)$:

$$A_1 / A_2 = (c_1/b_2, a_1/a_2, b_1/c_2), \quad c_1 \ge 0, \quad c_2 \ge 0. \quad (5.6)$$

## 5.3.2 Linguistic Values

In fuzzy decision environments, two preference ratings can be used. They are fuzzy numbers and linguistic values characterized by fuzzy numbers (Zadeh 1975a, b, 1976). Depending on practical needs, DMs may apply one or both of them. In this research, linguistic values characterized by triangular fuzzy numbers have been used to evaluate the importance weights of all criteria and the appropriateness of alternatives versus various subjective criteria above the alternative level.

## 5.3.3 Ranking of Triangular Fuzzy Numbers

In fuzzy decision-making environment, ranking the alternatives under consideration is important and essential. For matching the fuzzy MCDM algorithm developed in this work, and powerfulness in problem solving, the graded mean integration representation method proposed by (Chen and Hsieh, 2000) has been used to rank the final ratings of alternatives. Let $A_i = (c_i, a_i, b_i)$, $i = 1,2,...,n$ be $n$ triangular fuzzy numbers. By the graded mean integration representation method, the graded mean integration representation $R(A_i)$ of $A_i$ is

$$R(A_i) = \frac{c_i + 4a_i + b_i}{6} \tag{5.7}$$

Suppose $R(A_i)$ and $R(A_j)$ are the graded mean integration representations of the triangular fuzzy numbers $A_i$ and $A_j$ , respectively.

Define that:
$$\begin{aligned} A_i > A_j &\Leftrightarrow R(A_i) > R(A_j), \\ A_i < A_j &\Leftrightarrow R(A_i) < R(A_j), \\ A_i = A_j &\Leftrightarrow R(A_i) = R(A_j). \end{aligned} \tag{5.8}$$

## 5.3.4 Distance between Two Triangular Fuzzy Numbers

There are many methods can be used to characterize the inter-objects similarity (Liang et al. 2005). By considering the easy implementation and intuition, the distance measures based on triangular fuzzy numbers are utilized to build up the similarity between two objects. Because the (Chen and Hsieh, 2000) modified geometrical distance with distance parameter p = 2 can meet the concept of classical distance, and by considering the easy implementation and powerful, we utilize it to solve the distance between two triangular fuzzy numbers.

Let $A_i = (c_i, a_i, b_i), \quad i = 1,2,...,n$ and $A_j = (c_i, a_i, b_i), \quad j = 1,2,...,n$ be two triangular fuzzy numbers. Based on (Chen and Hsieh, 2000) method, the distance between $A_i$ and $A_j$, denoted by $d(A_i, A_j)$ is as follows:

$$d(A_i, A_j) = \left\{ \left[ (c_i - c_j)^2 + (a_i - a_j)^2 + (b_i - b_j)^2 \right] \big/ 4 \right\}^{1/2} \tag{9}$$

## 5.4 Grey Relational Analysis (GRA)

During the decision making process, the decision-makers try to gather as much information as possible through surveys, investigations, sampling, etc. so as to reach the aspired decision, but obtaining all the information remains impossibility; therefore decisions are usually made in grey process, i.e. without complete information. This is where GRA, finds application in solving MCDM problems. In comparison with conventional evaluation models, the GRA possesses following advantages (Deng, 1989; Shi, 1990; Wu, 1996): calculations are simple, requires small samples, sample distribution is not needed as per probability theory, no confliction between subjective and objective data sets and it is effective in dealing with distributed statistics.

## 5.5 Fuzzy Based Grey Multi-Criteria Decision Making

This study attempts to apply fuzzy set theory and grey relational analysis to the evaluation (appraisement as well as benchmarking) of SC performance extent based on an integrated criteria hierarchy. Due to subjectivity of evaluation information, involvement of a decision-making group is indeed essential to facilitate the said decision-making. The expert group must follow the proposed six step procedure.

i. Identifying decision objective and an evaluation committee group – Gathering the relevant information to evaluate the advantages and disadvantages and monitoring the results to ensure the objective is able to achieve. This is necessary to form an expert committee for group knowledge to achieve the targeted goals.

ii. Developing evaluation by quantitative scale – To establish a set of aspects and criteria for evaluation, the criteria have the nature of complicated relationships within the criteria. Choose appropriate preference ratings for criteria weights and the superiority of alternative versus various criteria above alternative level.

iii. Calculate the subjective weights of all criteria above the alternative level.

iv. Solve the superiority of all alternatives versus all criteria above the alternative level.

v. Calculate the integration weights of all criteria above alternative level.

vi. Calculate the fuzzy grey relation grade (GRG) of all compared alternatives to reference alternative and select the optimal alternative.

Various criteria can be considered in a multi-criteria evaluation problem. Criteria used should be identified by considering the specific requirements of the problem. The criteria can be classified into two categories: (1) subjective criteria, which have linguistic/qualitative definition; (2) objective criteria, which are defined in monetary/quantitative terms.

Two preference scales are to be used. They are triangular fuzzy numbers and linguistic values characterized by triangular fuzzy numbers. Based on the practical needs, the DMs may apply one or both of them. In this work, weighting set W= {VL, L, ML, M, MH, H, VH} and rating set S= {VP, P, MP, F, MG, G, VG}, have been used to evaluate the importance weights of all criteria and the fuzzy ratings of alternatives versus various subjective criteria above the alternative level, respectively.

**1. Solve the subjective weights of all criteria above the alternative level**

Let $w_{kj} = (c_{kj}, a_{kj}, b_{kj}), 0 \le c_{kj} \le a_{kj} \le b_{kj} \le 1,\ k = 1,2,...,n;\ j = 1,2,...,r,$ be the importance degrees assigned to criterion $C_k$ by the decision-maker $DM_j$. Then, the weight $w_k$ of $C_k$ can be calculated by

$$w_k = \left(\frac{1}{r}\right) \otimes \left(w_{k1} \oplus w_{k2} \oplus ... \oplus w_{kj} \oplus ... \oplus w_{kr}\right) \tag{5.10}$$

By the extension principle, $w_k$ is also a triangular fuzzy number. That is, let

$$c_k = \sum_{j=1}^{r} c_{kj}/r, a_k = \sum_{j=1}^{r} a_{kj}/r, b_k = \sum_{j=1}^{r} b_{kj}/r \tag{5.11}$$

Then $w_k = (c_k, a_k, b_k)$

**2. Solve the superiority ratings of all alternatives versus all criteria above the alternative level**

Let $M_{ikj} = (q_{ikj}, o_{ikj}, f_{ikj}), 0 \le q_{ikj} \le o_{ikj} \le f_{ikj}; i = 1,2,...,m; k = 1,2,...,n; j = 1,2,...,r$, be the linguistic ratings assigned to alternative $A_i$ by the decision-maker $D_j$ for the subjective criterion $C_k$. Then, the linguistic rating $M_{ik}$ of alternative $A_i$ for the subjective criterion $C_k$ can be calculated by

$$M_{ik} = \left(\frac{1}{r}\right) \otimes \left(M_{ik1} \oplus ... \oplus M_{ikj} \oplus ... \oplus M_{ikr}\right), i = 1,2,...,m; k = 1,2,...,n. \tag{5.12}$$

Let $q_{ik} = \sum_{j=1}^{r} \frac{q_{ikj}}{r}, o_{ik} = \sum_{j=1}^{r} \frac{o_{ikj}}{r}, f_{ik} = \sum_{j=1}^{r} \frac{f_{ikj}}{r}$, then

$$M_{ik} = (q_{ik}, o_{ik}, f_{ik}), i = 1,2,...,m; k = 1,2,...,n. \tag{5.13}$$

**3. Calculate the integration weights of all criteria above alternative level**

Let $w_k = (c_k, a_k, b_k), k = 1,2,...,n,$ denote the subjective weights of $n$ criteria above alternative level. Allow $u_k, k = 1,2,...,n,$ to be the normalized subjective weight of all criteria above the alternative level. Define

$$u_k = \frac{R(w_k)}{\sum_{k=1}^{n} R(w_k)}, k = 1,2,...,n. \tag{5.14}$$

Here $R(F_i)$ is the graded mean integration representation method of fuzzy number $F_i = (c_i, a_i, b_i), i = 1,2,..., p$

$$R(F_i) = \frac{c_i + 4a_i + b_i}{6} \tag{5.15}$$

**4. Calculate the grey relational grade of all compared alternatives to reference alternative**

Let $X_i, i = 1,2,...,m$ be the superiority ratings of $m$ alternatives described by triangular fuzzy numbers of linguistic values characterized by triangular fuzzy numbers.

Let $X_0 = (X_{01}, X_{02},..., X_{0n})$ and $X_i = (X_{i1}, X_{i2},..., X_{in})(i = 1,2,..., m)$ be the referential sequence and comparative sequences, respectively. In addition, allow $d_{0i}(k)$ to be the distance of fuzzy difference between the referential pattern $X_{0k}$ and a comparative pattern $X_{ik}$, where $X_{0k}$ is the fuzzy message of $X_0$ and $X_{ik}$ is the fuzzy message of $X_i$ at point (criterion) $k$. Define $d_{0i}(k)$ as

$d_{0i}(k) = d(X_{0k}, X_{ik})$

Let $F_i = (c_i, a_i, b_i)$, $F_j = (c_j, a_j, b_j)$ be two triangular fuzzy numbers. Based on (Chen and Hsieh, 2000) method, the distance between $F_i$ and $F_j$, denoted by $d(F_i, F_j)$, is

$$d(F_i, F_j) = \left\{ \left[ (c_i - c_j)^2 + (a_i - a_j)^2 + (b_i - b_j)^2 \right] \Big/ 4 \right\}^{1/2} \tag{5.16}$$

**5. Define the grey relation coefficient (GRC) of $X_0$ and $X_i$ at point (criterion) $k$ as**

$$\gamma(X_{0k}, X_{ik}) = \frac{\left( \min_i \min_k d_{0i}(k) + \xi \max_i \max_k d_{0i}(k) \right)}{\left( d_{0i}(k) + \xi \max_i \max_k d_{0i}(k) \right)} \tag{5.17}$$

The GRC $\gamma(X_{0k}, X_{ik})$ can be utilized to reflect the grey relation of $X_i$ compared to $X_0$ at point (criterion) $k$.

In aforesaid equation, $\max_i \max_k d_{0i}(k)$ and $\min_i \min_k d_{0i}(k)$ denote the maximum and the minimum elements of the $d_{0i}(k)$, respectively. The distinguishing coefficient $\xi$, which is between 0 and 1, can be used to change the dimension of relative values of $\gamma(X_{0k}, X_{ik})$. In general, $\xi = 0.5$ is better when the relative conditions among series and elements are uncertain (Deng, 1989).

**6. Define the GRG of $X_i$ compared to $X_0$ as**

$$\gamma(X_0, X_i) = \sum_{k=1}^{n} u_k \times \gamma(X_{0k}, X_{ik}) \tag{5.18}$$

Here $u_k$ is the integration weight of criterion $C_k$.

When the number of GRC is too much and messages are too discrete, the GRG is used to characterize the grey relational grade of $X_i$ compared to $X_0$. When the GRG is larger indicates that the series $X_i$ and $X_0$ are highly related. On the contrary, these two series are lowly related when the GRG is littler.

## 5.6 Empirical Research

The evaluation index of key SC performance metrics platform adapted in this work is based on the reporting by (Gunasekaran et al., 2001). Table 5.1 presents key SC performance metrics. It consists of two level criteria hierarchy (Level I & II) in which strategic performance $C_1$, tactical performance $C_2$ and operational performance $C_3$ have been considered as main evaluation criterions (at Level I) followed by various sub-criterions (at level II). Since the theoretical work conceptualizes performance benchmarking of alternatives (candidate companies of the same industry); the said criteria-hierarchy (Table 5.1) has been used as a reference frame of assessing SC's performance extent. Based on Table 5.1, a questionnaire need to be prepared in which DMs would provide their expert judgment in regards of appropriateness rating of various sub-criterions (at Level II) as well as priority weight of main criterions and sub-criterions through linguistic terms (Table 5.2). Linguistic data are to be transformed into appropriate fuzzy numbers as depicted in Table 5.2, and then based on operational rules of fuzzy mathematics as well as fuzzy grey relation analysis; alternative companies are ranked based on their SC performance extent.

An approach based on 'fuzzy grey relation method' as proposed by (Liao et al., 2013) has been used towards SC performance benchmarking of alternative industries. Since most of the evaluation indices being subjective in nature; the aforesaid decision-making problem has been modified to work under fuzzy environment. In this context, the team of decision-makers' play an important role in providing decision information in relation to various SC performance indices (their weight as well as rating). In this research, the priority weights and corresponding appropriateness ratings (performance estimates) of individual SC performance indices have been expressed by linguistic variables collected from a decision-making group (experts). Linguistic information has been transformed into appropriate fuzzy number in accordance with a predefined fuzzy scale set by the decision-makers'.

In this empirical study, a decision-making problem has been formulated towards SC performance evaluation as well as benchmarking. In this problem, a number of candidate industries/enterprises (running under similar SC architecture) have been selected. The objective has been to compute SC performance index of the individual industry/enterprise and to derive performance ranking order of the same (Benchmarking). The procedural steps of performance evaluation framework have been explained below with detailed numerical illustrations. The various alternatives are nothing but candidate companies of the same industry operating under similar SC construct (Table 5.1). This part of work is completely theoretical exploring empirical data.

**Step 1:** Constitution of SC performance appraisement platform and the expert panel. Assume that a committee of five decision-makers' (DMs) (DM1, DM2, DM3, DM4, DM5) has been formed which constitutes individuals of management practice as well as academia to participle in the decision-making process. The expert group has been instructed to finalize a performance appraisement platform (Table 5.1) in understanding with different performance measures as well as metrics after conducting several brainstorming sessions. Next, the appropriate linguistic scale has been selected in order to express DM's subjective preferences in assigning priority weight as well as appropriateness rating of individual SC performance indices. These linguistic data have been converted into fuzzy data as per the scales selected (Table 5.2).

**Step 2:** In the initial stage, the expert group has finalized priority importance (linguistic weights) in relation to each of the Level I as well as Level II performance indices; which has been considered same for all the candidate alternatives.

**Step 3:** The expert group has then been instructed to visit candidate industries and put their linguistic judgment (opinion) in relation to ongoing performance of each SC performance index for the three alternative industries, as considered ($A_1$, $A_2$, $A_3$). Here Table 5.3 and Table 5.4 represented the priority weights against individual $2^{nd}$ and $1^{st}$ level sub-criterions as given by the decision makers; Table 5.5, 5.6 and 5.7 represented the appropriateness ratings against $2^{nd}$ level sub-criterions as given by the decision makers of $A_1$, $A_2$ and $A_3$, respectively.

**Step 4:** Linguistic judgment has been further transformed into appropriate fuzzy number (as per the scales chosen. Using 'fuzzy average rule', aggregated fuzzy weight (for individual Level II and Level I indices) as well as aggregated fuzzy rating (of individual Level II indices, for alternative enterprises) have been computed. Using 'fuzzy weighted average rule', computed fuzzy ratings corresponding to individual Level I performance indices have been computed.

Appropriateness rating for each of the Level I evaluation index $U_i$ (rating of $i_{th}$ index) has been computed as follows:

$$U_i = \frac{\Sigma U_{ij} \otimes w_{ij}}{\Sigma w_{ij}} \quad (5.19)$$

In this expression (Eq. 5.19) $U_{ij}$ has been denoted as aggregated appropriateness rating and aggregated fuzzy weights obtained against $j_{th}$ index (at Level II) which is under $i_{th}$ index in the 1st level. Also $w_{ij}$ is the aggregated fuzzy weight against $j_{th}$ index (at Level II) which is under $i_{th}$ index at Level I. By using the Eq. (5.10), we calculated the aggregated fuzzy weight and aggregated fuzzy rating of 2nd level indices (for candidate alternatives $A_1$, $A_2$, $A_3$, respectively) and shown in Table 5.8.

The Fuzzy Index has been computed as:

$$U = \frac{\sum_{i=1}^{m} U_i \otimes w_i}{\sum_{i=1}^{m} w_i} \quad (5.20)$$

In this expression (Eq. 5.20) $U_i$ denotes the computed fuzzy appropriateness rating (obtained using Eq. 5.19) against $i^{th}$ index at 1st level. Also $w_i$ is the aggregated fuzzy importance against $i^{th}$ index in 1st level. Table 5.9 concluded the aggregated fuzzy weight and computed fuzzy rating of individual 1st level indices ($A_1$, $A_2$, and $A_3$), respectively.

**Step 5:** Then, develop a fuzzy multi-criteria group decision making (FMCGDM) matrix based on three alternatives and three main criterions/indices (Table 5.10).

**Step 6:** Integration weights of all criterions (Level I) have been computed. The weights are: 0.3299, 0.3401, and 0.3299.

**Step 7:** Grey relation coefficients against individual criterions (for each alternatives) (Table 5.11) and finally, grey relation grades (GRG) of all compared alternatives to reference alternative have been computed next (Table 5.12).

As per the analysis it has been found that the second alternative ($A_2$) appeared as best ranked amongst the three possible alternatives. It can be seen that this method can provide reliable results and be treated as one of the Multi-Criteria Decision Making (MCDM) techniques. Consequently, this multi-criteria analysis method is of practical use in solving real life multi-criteria analysis decision problems.

## 5.7 Managerial Implications

Selecting a best alternative by considering multiple performance criteria is very important in organizational routine works. In this study criterions have arranged from the previous literatures to estimate SC performance extent. Focus has been on developing qualitative evaluates of key SCM performance. A consequence of expressing representation of uncertainty in the evaluation model formulation is the fuzzy set theory, which reflects these uncertainties with represented by Triangular Fuzzy Numbers (TFNs). This study explored TFNs to represent linguistic variables (evaluation information) in dealing with fuzzy subjective judgments by evaluators and reduces the evaluator cognitive burden during evaluation processes. This method has been found fruitful for evaluating the best SC alternative decision making in relation to the estimated performance level.

In conclusion, this study contributes to, in particular, the literatures by: (i) proposing a research framework that relates determinants in grey relational method and knowledge management capacities; (ii) developing valid and reliable measures for the criteria based on expert's qualitative information and (iii) proposed a decision-making approach to evaluate the organization using grey relational method in uncertainty.

Since this is an MCDM problem, it is better to employ MCDM methods for reaching an effective solution. The fuzzy grey relational method can be used not only as a way to handle the inner dependences within a set of aspects and criteria, but also as a way of producing more valuable information for decision making. Grey relational method can generate reliable solutions efficiently when they are benchmarked with the results from the existing methodologies.

All criteria may not consider being of equal weight; however, this can be adjusted based upon a decision maker's judgment, and different selections will produce different results. Dealing with the MCDM problem, it is better to employ MCDM methods for reaching an effective problem solving. This study proposed fuzzy grey relational method which is comprehensive and applicable to other industry that require group decision making in a fuzzy environment to segment complex interdependency criteria and decision making. The fuzzy grey relational method is a relatively new MCDM method which can deal with all kinds of information vagueness systematically.  Moreover, the results of the present study illustrates that the grey relation method is simple and straightforward in calculations and prioritizing. Therefore, it is very suitable for solving MCDM problems. Furthermore, using the suggested analytical procedure, it can effectively handle any problem of selection with multi-faceted criteria. Aforesaid MCDM approach is seemed very helpful since it bears significant managerial implications. SC Performance benchmarking helps in identifying the best organization (it’s SC); best practices can be identified as well. Industries can follow their peers in order to boost up overall SC performance extent.

## 5.8 Concluding Remarks

The foregoing work exhibits fuzzy grey relation based decision support system for SC performance benchmarking. The objective was to benchmark alternative industries (their SCs) in relation the overall performance level of the SC. Application potential of the grey-Fuzzy MECDM approach has been clearly justified through this research. Empirical study reflects in-depth understanding of aforesaid approach. Real case study may be performed in future to improve the said appraisement platform.

Table 5.1: A list of Key SCM Performance metrics (Gunasekaran et al., 2001)

| Performance indices (Level I) | Performance indices (Level II) |
|---|---|
| Strategic performance, $C_1$ | Total supply chain cycle time, $C_{11}$ |
| | Total cash flow time, $C_{12}$ |
| | Customer query time, $C_{13}$ |
| | Level of customer perceived value of product, $C_{14}$ |
| | Net profit vs. productivity ratio, $C_{15}$ |
| | Rate of return on investment, $C_{16}$ |
| | Range of products and services, $C_{17}$ |
| | Variations against budget, $C_{18}$ |
| | Order lead time, $C_{19}$ |
| | Flexibility of service systems to meet particular customer needs, $C_{1,10}$ |
| | Buyer-supplier partnership level, $C_{1,11}$ |
| | Supplier lead time against industry norms, $C_{1,12}$ |
| | Level of supplier's defect free deliveries, $C_{1,13}$ |
| | Delivery lead time, $C_{1,14}$ |
| | Delivery performance, $C_{1,15}$ |
| Tactical performance, $C_2$ | Accuracy of forecasting techniques, $C_{21}$ |
| | Product development cycle time, $C_{22}$ |
| | Order entry methods, $C_{23}$ |
| | Effectiveness of delivery invoice methods, $C_{24}$ |
| | Purchase order cycle time, $C_{25}$ |
| | Planned process cycle time, $C_{26}$ |
| | Effectiveness of master production schedule, $C_{27}$ |
| | Supplier assistance in solving technical problems, $C_{28}$ |
| | Suppliers ability to respond to quality problems, $C_{29}$ |
| | Supplier cost saving initiatives, $C_{2,10}$ |
| | Supplier's booking in procedures, $C_{2,11}$ |
| | Delivery reliability, $C_{2,12}$ |
| | Responsiveness to urgent deliveries, $C_{2,13}$ |
| | Effectiveness of distribution planning schedule, $C_{2,14}$ |
| Operational performance, $C_3$ | Cost per operation hour, $C_{31}$ |
| | Information carrying cost, $C_{32}$ |
| | Capacity utilization, $C_{33}$ |
| | Total inventory cost (Incoming stock level, Work-in-Progress, Scrap value, Finished goods in transit), $C_{34}$ |
| | Supplier rejection rate, $C_{35}$ |
| | Quality of delivery documentation, $C_{36}$ |
| | Efficiency of purchase order cycle time, $C_{37}$ |
| | Frequency of delivery, $C_{38}$ |
| | Driver reliability for performance, $C_{39}$ |
| | Quality of delivered goods, $C_{3,10}$ |
| | Achievement of defect free deliveries, $C_{3,11}$ |

Table 5.2: Definitions of linguistic variables for the ratings and the importance of each criterion

| Linguistic variables(Rating) | Linguistic variables(importance) | Triangular fuzzy numbers |
|---|---|---|
| Very Poor (VP) | Very Low (VL) | (0,0,0.167) |
| Poor (P) | Low (L) | (0,0.167,0.333) |
| Moderately Poor (MP) | Medium Low (ML) | (0.167,0.333,0.5) |
| Fair (F) | Medium (M) | (0.333,0.5,0.668) |
| Moderately Good (MG) | Medium High (MH) | (0.5,0.668,0.835) |
| Good (G) | High (H) | (0.668,0.835,1) |
| Very Good (VG) | Very High (VH) | (0.835,1,1) |

Table 5.3: Priority weights against individual 2nd level sub-criterions as given by the DMs

| Performance metrics | Priority weights in linguistic term | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | VH | VH | H | H | H |
| $C_{12}$ | H | H | H | H | VH |
| $C_{13}$ | H | VH | H | VH | H |
| $C_{14}$ | VH | VH | VH | VH | VH |
| $C_{15}$ | H | MH | H | H | H |
| $C_{16}$ | MH | H | VH | H | H |
| $C_{17}$ | H | H | H | VH | H |
| $C_{18}$ | MH | MH | H | H | H |
| $C_{19}$ | VH | VH | H | H | VH |
| $C_{1,10}$ | VH | VH | VH | VH | VH |
| $C_{1,11}$ | H | H | H | H | VH |
| $C_{1,12}$ | VH | VH | H | H | H |
| $C_{1,13}$ | H | VH | VH | VH | VH |
| $C_{1,14}$ | H | VH | VH | H | VH |
| $C_{1,15}$ | H | H | H | H | H |
| $C_{21}$ | VH | VH | VH | VH | VH |
| $C_{22}$ | H | MH | H | H | H |
| $C_{23}$ | MH | H | H | H | H |
| $C_{24}$ | H | H | H | VH | H |
| $C_{25}$ | MH | MH | H | H | H |
| $C_{26}$ | VH | VH | VH | H | VH |
| $C_{27}$ | VH | VH | H | VH | VH |
| $C_{28}$ | H | H | VH | H | VH |
| $C_{29}$ | VH | VH | VH | H | H |
| $C_{2,10}$ | VH | VH | VH | VH | VH |
| $C_{2,11}$ | H | MH | H | H | H |
| $C_{2,12}$ | MH | H | VH | H | H |
| $C_{2,13}$ | H | H | H | VH | VH |
| $C_{2,14}$ | MH | H | H | H | H |
| $C_{31}$ | VH | VH | H | H | VH |
| $C_{32}$ | VH | VH | H | VH | VH |
| $C_{33}$ | H | H | H | H | VH |
| $C_{34}$ | VH | VH | H | H | H |
| $C_{35}$ | VH | VH | H | H | VH |
| $C_{36}$ | H | MH | H | H | H |
| $C_{37}$ | MH | H | VH | H | H |
| $C_{38}$ | H | H | H | VH | H |
| $C_{39}$ | MH | MH | H | H | H |
| $C_{3,10}$ | VH | VH | H | H | VH |
| $C_{3,11}$ | VH | VH | H | H | VH |

Table 5.4: Priority weights against individual 1st level criterions as given by the decision-makers

| Performance metrics | Priority weights in linguistic term | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_1$ | VH | VH | H | H | H |
| $C_2$ | H | VH | H | VH | VH |
| $C_3$ | H | VH | H | VH | H |

Table 5.5: Appropriateness ratings against 2nd level sub-criterions as given by the decision-makers **(Alternative 1)**

| Performance metrics | Priority weights in linguistic term | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | F | F | MP | F | F |
| $C_{12}$ | F | F | MG | MG | MG |
| $C_{13}$ | MG | MG | MG | MG | F |
| $C_{14}$ | MP | F | F | F | MP |
| $C_{15}$ | MP | F | MP | F | MP |
| $C_{16}$ | F | MG | MG | MG | MG |
| $C_{17}$ | F | F | MG | MG | F |
| $C_{18}$ | MG | F | MG | F | F |
| $C_{19}$ | F | F | MG | MG | MG |
| $C_{1,10}$ | MG | F | MG | MG | F |
| $C_{1,11}$ | MP | F | F | F | MP |
| $C_{1,12}$ | MP | F | MP | F | MP |
| $C_{1,13}$ | F | MG | MG | MG | MG |
| $C_{1,14}$ | F | F | F | MG | F |
| $C_{1,15}$ | MG | G | G | MG | G |
| $C_{21}$ | F | MG | G | F | MG |
| $C_{22}$ | F | MG | MG | MG | MG |
| $C_{23}$ | MP | F | MG | MG | F |
| $C_{24}$ | MP | F | F | F | MP |
| $C_{25}$ | MP | F | MP | F | MP |
| $C_{26}$ | F | MG | MG | MG | MG |
| $C_{27}$ | F | F | MG | MG | F |
| $C_{28}$ | MG | G | G | MG | G |
| $C_{29}$ | F | MG | G | F | MG |
| $C_{2,10}$ | F | F | MG | MG | MG |
| $C_{2,11}$ | MG | F | MG | MG | F |
| $C_{2,12}$ | MG | F | F | F | MP |
| $C_{2,13}$ | MG | MG | MG | MG | F |
| $C_{2,14}$ | MP | F | F | MG | MP |
| $C_{31}$ | MP | F | MP | F | MP |
| $C_{32}$ | F | MG | MG | MG | MG |
| $C_{33}$ | F | F | F | MG | F |
| $C_{34}$ | MG | G | G | MG | G |
| $C_{35}$ | F | MG | G | F | MG |
| $C_{36}$ | F | MG | MG | MG | MG |
| $C_{37}$ | MP | F | MG | MG | F |
| $C_{38}$ | MP | F | F | F | MP |
| $C_{39}$ | MP | F | MG | F | MP |
| $C_{3,10}$ | F | MG | MG | MG | MG |
| $C_{3,11}$ | F | F | F | MG | F |

Table 5.6: Appropriateness ratings against 2nd level sub-criterions as given by the decision-makers **(Alternative 2)**

| Performance metrics | Priority weights in linguistic term | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | G | VG | G | VG | VG |
| $C_{12}$ | VG | G | VG | G | VG |
| $C_{13}$ | G | G | G | G | G |
| $C_{14}$ | VG | G | VG | G | VG |
| $C_{15}$ | MG | G | G | G | G |
| $C_{16}$ | MG | MG | MG | MG | MG |
| $C_{17}$ | G | G | G | VG | VG |
| $C_{18}$ | MG | MG | MG | MG | MG |
| $C_{19}$ | F | MG | MG | G | MG |
| $C_{1,10}$ | F | F | F | MG | G |
| $C_{1,11}$ | VG | VG | G | G | G |
| $C_{1,12}$ | G | VG | VG | MG | MG |
| $C_{1,13}$ | G | G | G | VG | VG |
| $C_{1,14}$ | VG | G | VG | G | VG |
| $C_{1,15}$ | G | G | G | G | G |
| $C_{21}$ | VG | G | VG | G | VG |
| $C_{22}$ | MG | G | G | G | G |
| $C_{23}$ | MG | MG | MG | MG | MG |
| $C_{24}$ | G | G | G | VG | VG |
| $C_{25}$ | G | MG | MG | MG | G |
| $C_{26}$ | G | MG | MG | G | G |
| $C_{27}$ | G | F | F | MG | G |
| $C_{28}$ | VG | VG | G | G | G |
| $C_{29}$ | G | VG | G | MG | MG |
| $C_{2,10}$ | G | VG | G | VG | VG |
| $C_{2,11}$ | VG | G | G | G | VG |
| $C_{2,12}$ | G | G | G | G | G |
| $C_{2,13}$ | VG | G | G | G | G |
| $C_{2,14}$ | F | F | F | MG | G |
| $C_{31}$ | G | VG | G | G | G |
| $C_{32}$ | G | VG | VG | F | MG |
| $C_{33}$ | G | G | G | VG | VG |
| $C_{34}$ | G | G | VG | G | VG |
| $C_{35}$ | G | G | G | G | G |
| $C_{36}$ | G | G | VG | G | VG |
| $C_{37}$ | G | G | G | G | G |
| $C_{38}$ | G | MG | MG | MG | MG |
| $C_{39}$ | G | G | G | VG | VG |
| $C_{3,10}$ | G | MG | MG | F | G |
| $C_{3,11}$ | G | MG | MG | G | G |

Table 5.7: Appropriateness ratings against 2nd level sub-criterions as given by the decision-makers **(Alternative 3)**

| Performance metrics | Priority weights in linguistic term | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | P | P | P | MP | MP |
| $C_{12}$ | P | MP | MP | MP | MP |
| $C_{13}$ | F | F | F | MP | F |
| $C_{14}$ | F | F | F | F | F |
| $C_{15}$ | F | MP | MG | MP | MG |
| $C_{16}$ | F | F | F | MP | F |
| $C_{17}$ | MP | F | MP | F | MP |
| $C_{18}$ | P | MP | P | P | P |
| $C_{19}$ | F | F | F | F | F |
| $C_{1,10}$ | F | P | P | MP | MP |
| $C_{1,11}$ | F | MG | MG | MP | MP |
| $C_{1,12}$ | F | F | F | MP | F |
| $C_{1,13}$ | F | F | F | F | F |
| $C_{1,14}$ | F | MP | MG | MP | MG |
| $C_{1,15}$ | F | F | F | MP | F |
| $C_{21}$ | MP | F | MP | F | MP |
| $C_{22}$ | P | MP | P | P | P |
| $C_{23}$ | F | F | F | F | F |
| $C_{24}$ | P | P | P | MG | MP |
| $C_{25}$ | P | MP | MP | MG | MP |
| $C_{26}$ | F | F | MG | MP | F |
| $C_{27}$ | F | F | F | MP | F |
| $C_{28}$ | MG | F | MP | F | MP |
| $C_{29}$ | P | MP | P | P | P |
| $C_{2,10}$ | MG | F | F | F | F |
| $C_{2,11}$ | MG | P | P | MP | MP |
| $C_{2,12}$ | F | MG | MG | MP | MP |
| $C_{2,13}$ | F | F | F | MP | F |
| $C_{2,14}$ | F | F | F | F | F |
| $C_{31}$ | F | MG | MG | MP | MG |
| $C_{32}$ | F | F | F | MP | F |
| $C_{33}$ | MP | F | MP | F | MP |
| $C_{34}$ | P | MP | P | P | P |
| $C_{35}$ | F | F | F | F | F |
| $C_{36}$ | P | P | P | MG | MG |
| $C_{37}$ | P | MP | MP | MG | MG |
| $C_{38}$ | F | F | MG | MP | F |
| $C_{39}$ | F | F | F | MP | F |
| $C_{3,10}$ | MP | F | MG | F | MP |
| $C_{3,11}$ | P | MP | P | P | P |

Table 5.8: Aggregated fuzzy weight and aggregated fuzzy rating **($A_1$, $A_2$, $A_3$)** of 2nd level indices

| 2nd level indices | Aggregated fuzzy weight, $w_{ij}$ | Aggregated fuzzy rating, Alternative 1 ($A_1$) | Aggregated fuzzy rating, Alternative 2 ($A_2$) | Aggregated fuzzy rating, Alternative 3 ($A_3$) |
|---|---|---|---|---|
| $C_{11}$ | (0.7348, 0.9010, 1.0000) | (0.2998, 0.4666, 0.6344) | (0.7682, 0.9340, 1.0000) | (0.0668, 0.2334, 0.3998) |
| $C_{12}$ | (0.7041, 0.8680, 1.0000) | (0.4332, 0.6008, 0.7682) | (0.7682, 0.9340, 1.0000) | (0.1336, 0.2998, 0.4666) |
| $C_{13}$ | (0.7348, 0.9010, 1.0000) | (0.4666, 0.6344, 0.8016) | (0.6680, 0.8350, 1.0000) | (0.2998, 0.4666, 0.6344) |
| $C_{14}$ | (0.8350, 1.0000, 1.0000) | (0.2666, 0.4332, 0.6008) | (0.7682, 0.9340, 1.0000) | (0.3330, 0.5000, 0.6680) |
| $C_{15}$ | (0.6344, 0.8016, 0.9670) | (0.2334, 0.3998, 0.5672) | (0.6344, 0.8016, 0.9670) | (0.3334, 0.5004, 0.6676) |
| $C_{16}$ | (0.6678, 0.8346, 0.9670) | (0.4666, 0.6344, 0.8016) | (0.5000, 0.6680, 0.8350) | (0.2998, 0.4666, 0.6344) |
| $C_{17}$ | (0.7041, 0.8680, 1.0000) | (0.3998, 0.5672, 0.7348) | (0.7348, 0.9010, 1.0000) | (0.2334, 0.3998, 0.5672) |
| $C_{18}$ | (0.6008, 0.7682, 0.9340) | (0.3998, 0.5672, 0.7348) | (0.5000, 0.6680, 0.8350) | (0.0334, 0.2002, 0.3664) |
| $C_{19}$ | (0.7682, 0.9340, 1.0000) | (0.4332, 0.6008, 0.7682) | (0.5002, 0.6678, 0.8346) | (0.3330, 0.5000, 0.6680) |
| $C_{1,10}$ | (0.8350, 1.0000, 1.0000) | (0.4332, 0.6008, 0.7682) | (0.4334, 0.6006, 0.7678) | (0.1334, 0.3000, 0.4668) |
| $C_{1,11}$ | (0.7041, 0.8680, 1.0000) | (0.2666, 0.4332, 0.6008) | (0.7348, 0.9010, 1.0000) | (0.3334, 0.5004, 0.6676) |
| $C_{1,12}$ | (0.7348, 0.9010, 1.0000) | (0.2334, 0.3998, 0.5672) | (0.6676, 0.8342, 0.9340) | (0.2998, 0.4666, 0.6344) |
| $C_{1,13}$ | (0.8016, 0.9670, 1.0000) | (0.4666, 0.6344, 0.8016) | (0.7348, 0.9010, 1.0000) | (0.3330, 0.5000, 0.6680) |
| $C_{1,14}$ | (0.7682, 0.9340, 1.0000) | (0.3664, 0.5336, 0.7014) | (0.7682, 0.9340, 1.0000) | (0.3334, 0.5004, 0.6676) |
| $C_{1,15}$ | (0.6680, 0.8350, 1.0000) | (0.6008, 0.7682, 0.9340) | (0.6680, 0.8350, 1.0000) | (0.2998, 0.4666, 0.6344) |
| $C_{21}$ | (0.8350, 1.0000, 1.0000) | (0.4668, 0.6342, 0.8012) | (0.7682, 0.9340, 1.0000) | (0.2334, 0.3998, 0.5672) |
| $C_{22}$ | (0.6344, 0.8016, 0.9670) | (0.4666, 0.6344, 0.8016) | (0.6344, 0.8016, 0.9670) | (0.0334, 0.2002, 0.3664) |
| $C_{23}$ | (0.6344, 0.8016, 0.9670) | (0.3666, 0.5338, 0.7012) | (0.5000, 0.6680, 0.8350) | (0.3330, 0.5000, 0.6680) |
| $C_{24}$ | (0.7041, 0.8680, 1.0000) | (0.2666, 0.4332, 0.6008) | (0.7348, 0.9010, 1.0000) | (0.1334, 0.3004, 0.4668) |
| $C_{25}$ | (0.6008, 0.7682, 0.9340) | (0.2334, 0.3998, 0.5672) | (0.5672, 0.7348, 0.9010) | (0.1822, 0.3668, 0.5336) |
| $C_{26}$ | (0.8016, 0.9670, 1.0000) | (0.4666, 0.6344, 0.8016) | (0.6008, 0.7682, 0.9340) | (0.3332, 0.5002, 0.6678) |
| $C_{27}$ | (0.8016, 0.9670, 1.0000) | (0.3998, 0.5672, 0.7348) | (0.5004, 0.6676, 0.8342) | (0.2998, 0.4666, 0.6344) |
| $C_{28}$ | (0.7348, 0.9010, 1.0000) | (0.6008, 0.7682, 0.9340) | (0.7348, 0.9010, 1.0000) | (0.2334, 0.3998, 0.5672) |
| $C_{29}$ | (0.7682, 0.9340, 1.0000) | (0.4668, 0.6342, 0.8012) | (0.6342, 0.8012, 0.9340) | (0.0334, 0.2002, 0.3664) |
| $C_{2,10}$ | (0.8350, 1.0000, 1.0000) | (0.4332, 0.6008, 0.7682) | (0.7682, 0.9340, 1.0000) | (0.3664, 0.5336, 0.7014) |
| $C_{2,11}$ | (0.6344, 0.8016, 0.9670) | (0.4332, 0.6008, 0.7682) | (0.7348, 0.9010, 1.0000) | (0.1668, 0.3336, 0.5002) |
| $C_{2,12}$ | (0.6678, 0.8346, 0.9670) | (0.3332, 0.5002, 0.6678) | (0.6680, 0.8350, 1.0000) | (0.3334, 0.5004, 0.6676) |
| $C_{2,13}$ | (0.7348, 0.9010, 1.0000) | (0.4666, 0.6344, 0.8016) | (0.7014, 0.8680, 1.0000) | (0.2998, 0.4666, 0.6344) |
| $C_{2,14}$ | (0.6344, 0.8016, 0.9670) | (0.3000, 0.4668, 0.6342) | (0.4334, 0.6006, 0.7678) | (0.3330, 0.5000, 0.6680) |
| $C_{31}$ | (0.7682, 0.9340, 1.0000) | (0.2334, 0.3998, 0.5672) | (0.7014, 0.8680, 1.0000) | (0.3334, 0.5004, 0.6676) |
| $C_{32}$ | (0.8016, 0.9670, 1.0000) | (0.4666, 0.6344, 0.8016) | (0.6342, 0.8006, 0.9006) | (0.2998, 0.4666, 0.6344) |
| $C_{33}$ | (0.7041, 0.8680, 1.0000) | (0.3664, 0.5336, 0.7014) | (0.7348, 0.9010, 1.0000) | (0.2334, 0.3998, 0.5672) |
| $C_{34}$ | (0.7348, 0.9010, 1.0000) | (0.6008, 0.7014, 0.9340) | (0.7348, 0.9010, 1.0000) | (0.0334, 0.2002, 0.3664) |
| $C_{35}$ | (0.7682, 0.9340, 1.0000) | (0.4668, 0.6342, 0.8012) | (0.6680, 0.8350, 1.0000) | (0.3330, 0.5000, 0.6680) |
| $C_{36}$ | (0.6344, 0.8016, 0.9670) | (0.4666, 0.6344, 0.8016) | (0.7348, 0.9010, 1.0000) | (0.2000, 0.3674, 0.5338) |
| $C_{37}$ | (0.6678, 0.8346, 0.9670) | (0.3666, 0.5338, 0.7012) | (0.6680, 0.8350, 1.0000) | (0.2668, 0.4338, 0.6006) |

Table 5.8 (Continued)

| $2^{nd}$ level indices | Aggregated fuzzy weight, $w_{ij}$ | Aggregated fuzzy rating, Alternative 1 ($A_1$) | Aggregated fuzzy rating, Alternative 2 ($A_2$) | Aggregated fuzzy rating, Alternative 3 ($A_3$) |
|---|---|---|---|---|
| $C_{38}$ | (0.7041, 0.8680, 1.0000) | (0.2666, 0.4332, 0.6008) | (0.5336, 0.7014, 0.8680) | (0.3332, 0.5002, 0.6678) |
| $C_{39}$ | (0.6008, 0.7682, 0.9340) | (0.3000, 0.4668, 0.6342) | (0.7348, 0.9010, 1.0000) | (0.2998, 0.4666, 0.6344) |
| $C_{3,10}$ | (0.7682, 0.9340, 1.0000) | (0.4666, 0.6344, 0.8016) | (0.5338, 0.7012, 0.8676) | (0.3000, 0.4668, 0.6342) |
| $C_{3,11}$ | (0.7682, 0.9340, 1.0000) | (0.3664, 0.5336, 0.7014) | (0.6008, 0.7682, 0.9340) | (0.2998, 0.4666, 0.6344) |

Table 5.9: Aggregated fuzzy weight and computed fuzzy rating **($A_1$, $A_2$, $A_3$)** of $1^{st}$ level indices

| $1^{st}$ level indices | Aggregated fuzzy weight, $w_i$ | Computed fuzzy rating, Alternative 1 ($A_1$) | Computed fuzzy rating, Alternative 2 ($A_2$) | Computed fuzzy rating, Alternative 3 ($A_3$) |
|---|---|---|---|---|
| $C_1$ | (0.7348, 0.9010, 1.0000) | (0.2813, 0.5512, 0.9812) | (0.4823, 0.8911, 1.2903) | (0.1872, 0.4218, 0.8025) |
| $C_2$ | (0.7682, 0.9340, 1.0000) | (0.3002, 0.5787, 1.0207) | (0.4701, 0.8118, 1.2935) | (0.1744, 0.4070, 0.7863) |
| $C_3$ | (0.7348, 0.9010, 1.0000) | (0.2908, 0.5659, 1.0043) | (0.4802, 0.8262, 1.2000) | (0.1952, 0.4345, 0.8244) |

Table 5.10: Fuzzy multi-criteria group decision making (FMCGDM) matrix

| Alternatives | $C_1$ | $C_2$ | $C_3$ |
|---|---|---|---|
| $A_1$ | (0.2813, 0.5512, 0.9812) | (0.3002, 0.5787, 1.0207) | (0.2908, 0.5659, 1.0043) |
| $A_2$ | (0.4823, 0.8911, 1.2903) | (0.4701, 0.8118, 1.2935) | (0.4802, 0.8262, 1.2000) |
| $A_3$ | (0.1872, 0.4218, 0.8025) | (0.1744, 0.4070, 0.7863) | (0.1952, 0.4345, 0.8244) |

Table 5.11: Computation of grey relational coefficient (GRC)

| Alternatives | GRC of $C_1$ | GRC of $C_2$ | GRC of $C_3$ |
|---|---|---|---|
| A1 | 0.4241 | 0.4732 | 0.4486 |
| A2 | 1.0000 | 1.0000 | 1.0000 |
| A3 | 0.3333 | 0.3334 | 0.3333 |

Table 5.12: Alternative ranking based on GRG

| Alternatives | GRG | Ranking order |
|---|---|---|
| A1 | 0.4440 | 2 |
| A2 | 1.0204 | 1 |
| A3 | 0.3299 | 3 |

# CHAPTER 6

## Supply Chain Performance Benchmarking by Grey Theory and Grey-MULTIMOORA

## 6.1 Overview

Present work aims to develop efficient decision-support systems towards supply chain performance appraisement as well as benchmarking and to facilitate various decision makings at managerial level. Supply chain performance can be assessed by multiple criteria/attributes, called performance indicators/indices. Most of them are intangible (subjective) in nature. Hence, the task of supply chain performance appraisement can be executed based on the judgment of the decision makers. Moreover, evaluation of quantitative performance metric appears very difficult due to involvement of ill-defined (vague) performance measures as well as metrics. In order to overcome this, the study explores theory of grey numbers in order to tackle incomplete and inconsistent subjective judgment of the decision-makers. Firstly, a grey-based decision support system has been postulated to evaluate a unique performance index of a supply chain; to identify ill-performing areas and to benchmark performance of candidate enterprises possessing similar supply chain architecture. Finally, grey-MOORA approach has been inculcated to provide a strong mathematic base of the said performance appraisement platform. Empirical data have been analyzed and results obtained thereof, have been reported to exhibit application potential of the decision-support systems in appropriate situation.

## 6.2 Introduction

A definition of supply chain (Stevens, 1989) is: A system whose constituent parts include material suppliers, production facilities, distribution services and customers linked together via the feed forward flow of materials and the feedback flow of information. Supply chain management (SCM) describes the discipline of optimizing the delivery of goods, services and related information from supplier to customer. It is concerned with the effectiveness of dealing with final customer's demand by the parties engaged in the provision of the product as a whole (Cooper et al., 1997). As defined by Chan and Burn (2002), a supply chain refers to an integrated and sequentially interrelated value system of suppliers, manufacturers, subcontractors, distributors and retailers working together with the prime purpose of creating value to the output for the ultimate end-users. From the beginning of this decade, this subject has been studied and practiced, and has been reported in the literature. While there are many ongoing research efforts on various aspects and areas of SCM, so far little attention has been given to the performance evaluation, and hence, to the measures and metrics of supply chains (Gunasekaran et al., 2001).

Performance measurement is critical for companies to improve supply chains' effectiveness and efficiency (Beamon, 1999; Shepherd and Günter, 2006). Performance measurement describes the feedback or information on activities with respect to meeting customer expectations and strategic objectives. It reflects the need for improvement in areas with unsatisfactory performance. Thus, efficiency and quality can be enhanced (Chan, 2003).

In supply chains with multiple vendors, manufacturers, distributors and retailers, whether regionally or globally dispersed, performance measurement is challenging because it is difficult to attribute performance results to one particular entity within the chain (Hervani et al., 2005).

Benchmarking is a popular tool which is used universally as a tool to improve organizations' performance and competitiveness in business life. The importance of benchmarking had made it explicitly included within the Malcolm Baldrige Award criteria. Its scope of application ranges from large firms to small businesses, public as well as semi-public sectors, and encompassed various types of industries (Ball, 2000; Davis, 1998; Jones, 1999; McAdam and Kelly, 2002).

There is still a lack of significant study of supply chain practices and its performance evaluation as well as benchmarking in developing countries, in general and India, in particular (Austin, 1990; Saad and Patel, 2006). The following section provides important insights into the work done so far in the area of supply chain performance appraisement, benchmarking and related decision making as documented in literature.

## 6.3 Research Background

Van Der Vorst et al. (1998) investigated the impact of Supply Chain Management on logistical performance indicators in food supply chains. Beamon (1999) investigated on the performance measures used in supply chain models and presented a framework for the selection of performance measurement systems for manufacturing supply chains. Performance measures were identified as necessary components in any supply chain performance measurement system, and new flexibility measures for supply chains were developed. Gunasekaran et al. (2001) developed a framework for measuring the strategic, tactical and operational level performance in a supply chain. The emphasis was on performance measures dealing with suppliers, delivery performance, customer-service, and inventory and logistics costs in a SCM. In developing the metrics, an effort was also made to align and relate them to customer satisfaction. Chan (2003) presented the formulization of both quantitative and qualitative performance measurements for SC logistics. Apart from the common criteria such as cost and quality, five other performance measurements were defined: resource utilization; flexibility; visibility; trust; and innovativeness. In addition, a multi-attribute decision-making technique, an analytic hierarchy process (AHP), was used to make decisions based on the priority of performance measures. This work outlined the application and particularly the pair wise comparison which helped to identify easily the importance of different performance measurements.

Kleijnen and Smits (2003) dealt with multiple metrics in SCM via the balanced scorecard which measured customers, internal processes, innovations, and finance. This paper distinguished four simulation types for SCM: (i) spreadsheet simulation, (ii) system dynamics, (iii) discrete-event simulation, and (iv) business games. These simulation types might explain the bullwhip effect, predict fill rate values, and educate and train users. Gunasekaran et al. (2004) developed a framework to promote a better understanding of the importance of SCM performance measurement and metrics. Using the existing literature and the results of an empirical study of selected British companies, the authors developed a framework, in hopes that it would stimulate more interest in this important area. Simatupang and Sridharan (2004) aimed to develop a benchmarking scheme for supply chain collaboration that linked collaborative performance metrics and collaborative enablers. The proposed benchmarking scheme could be used to examine the current status of supply chain collaboration among the participating members, identify performance gaps and systematize improvement initiatives. Hervani et al. (2005) addressed on various issues related to environmental (green) supply chain management performance measurement.

Saad and Patel (2006) focused on supply chain practices in the Indian automobile sector. This work identified the main motives and determinants for the adoption and implementation of supply chain management concepts. This work reviewed the relevance of the main models to measure the performance of supply chain in developing countries. This research proposed that the concept of supply chain performance is not fully embraced by the Indian automobile sector and highlights the difficulties associated with its implementation. Wong and Wong (2007) illustrated the use of Data Envelopment Analysis (DEA) in measuring internal supply chain performance. The information obtained from the DEA models would help managers to identify the inefficient operations and take the right remedial actions for continuous improvement. Aramyan et al. (2007) aimed to evaluate the usefulness of a novel conceptual model for supply chain performance measurement in an agri-food supply chain. It was concluded that four main categories of performance measures (i.e. efficiency, flexibility, responsiveness, and food quality) were identified as key performance components of the said supply chain performance measurement system.

Bhagwat and Sharma (2007) developed a balanced scorecard for supply chain management that measured and evaluated day-to-day business operations from following four perspectives: finance, customer, internal business process, and learning and growth. Kamalabadi et al. (2008) presented an approach to supply chain performance measurement by using Fuzzy Multi-Attribute Decision-Making (FMADM) method. Peng and Wong (2008) addressed benchmarking, definitions, concepts on supply chain benchmarking, problems in supply chain benchmarking, existing tools used in benchmarking, problems in existing tools and motivation of using DEA as a supply chain benchmarking tool. Thakkar et al. (2009) proposed an integrated supply chain performance measurement framework for the case of small and medium scale enterprises (SMEs). This research integrated the salient features of balanced scorecard (BSC) and supply chain operation reference (SCOR) model to deliver a comprehensive performance measurement framework for SMEs. Keebler and Plank (2009) provided a benchmark for organizations assessing the quality of their supply chain logistics performance measurement practices and helped in identifying opportunities for significant improvement.

Cai et al. (2009) proposed a framework using a systematic approach to improve the iterative key performance indicators (KPIs) accomplishment in a supply chain context. The proposed framework quantitatively analyzed the interdependent relationships among a set of KPIs. It could identify crucial KPI accomplishment costs and proposed performance improvement strategies for decision-makers in a supply chain. Bigliardi and Bottani (2010) developed a balanced scorecard (BSC) model that was designed and delimited for performance measurement in the food supply chain. Shaw et al. (2010) proposed a research agenda to examine whether environmental, i.e. green performance measures, could be integrated within an existing supply chain performance framework, explored what a meaningful industry-recognized environmental measure should look like, and provided understanding of the direct benefits of incorporating environmental measures within a supply chain performance framework. This study focused on four key areas: performance management, supply chain performance management, environmental management and benchmarking.

Adel El-Baz (2011) presented a performance measurement approach based on fuzzy set theory and the pair-wise comparison of Analytical Hierarchy Process (AHP), which ensured the consistency of the designer's assignments of importance of one factor over another to find the weight of each of the manufacturing activity in the departmental organization. In the proposed model, various input factors were selected, and treated as a linear membership function of fuzzy type. The approach provided an effective decision tool for the performance measurement of a supply chain in manufacturing environment. Janvier-James and Didier (2011) proposed a method to measure the extent of collaboration and trust in a supply chain as important components of organizational behavior that contributed to the performance improvement of supply chain. The proposed model for collaboration could be classified on the basis of functional supply chain processes or supply chain relationship. A Data Envelopment Analysis (DEA) was introduced to evaluate the level of collaborative practices.

Stefanović and Stefanović (2011) introduced the architecture of a pervasive Performance Measurement (PM) system in supply chain. The main system elements such as process model, metrics and data warehouse were described. Finally, a specialized PM web portal which enabled proactive performance monitoring and fosters the improvement and optimization was presented. Olugu and Wong (2011) aimed at establishing the validity of the measures and metrics for automobile green supply chain performance measurement. The study involved statistical tests using 16 measures and 72 corresponding metrics. These statistical tests included exploratory factor analysis to investigate the construct validity of the measures and their metrics, a confirmatory factor analysis to test the model fitness and a multiple regression analysis to test the criterion validity of the measures. Theeranuphattana et al. (2012) integrated three different approaches to multiple criteria decision analysis (MCDA)-the multi-attribute value theory (MAVT), the swing weighting method and the eigenvector procedure in order to develop a comprehensive assessment of supply chain performance. With this measurement method, supply chain managers could easily benchmark the performance of the whole system, and then analyze the effectiveness and efficiency of the supply chain.

Cirtita and Glaser-Segura (2012) developed a survey instrument to determine whether observed performance metrics correspond to the literature and to determine if performance metric systems were used to improve inter-firm performance. The survey instrument used in this study was based on SCOR performance attributes consisting of: delivery reliability, responsiveness, flexibility, costs, and asset management efficiency. The survey was completed by 73 members of the Council of Supply Chain Management Professionals (CSCMP) consisting of high-level managers representing US companies. Rostamy-Malkhalifeh and Mollaeian (2012) introduced a non-radial network DEA model for evaluating performance supply chain by considering intermediate production. Kocaoğlu et al. (2013) proposed an integrated approach which employed analytic hierarchy process (AHP) and technique for order preference by similarity to ideal solution (TOPSIS) together for the linking strategic objectives to supply chain operations.

Industrial organizations are moving toward more integrated supply chains (SCs) to remain competitive. To be effectively designed and managed, these SCs need to be measured and evaluated in a consistent way. The formal definition of different metrics, benchmarks and performance related concepts will facilitate the measurement process and enable the effective communication among the SC stakeholders. For this reason, it is important to acquire a common and unified understanding of the SC associated performance, process and structure concepts (Böhm et al., 2007).

A supply chain consists of different levels, which includes supplier, manufacturer, distributor, and consumer, and it is a network of companies which influence each other and affect one another's performance. Hence, an important issue in SCM is the development of integrated performance measurement systems (PMS). PMS serve different functions in supply chain and operations management. These are formal devices to control, formulate and communicate the company's strategy, and, as such, they primarily serve higher-level managers. But PMS can also support operational managers, to motivate and enable them to improve operations. A performance measurement framework assists in the process of performance measures building, by clarifying measurement boundaries, specifying performance measurement dimensions or views and may also provide initial intuitions into relationships among the dimensions (Rouse and Putterill, 2003; Chan, 2003). Singh et al. (2013) arranged twenty key performance indicators in order to measure the supply chain performance of organized garment retailing. The first most important group of key performance indicator was inventory metrics with seven indicators in this node. This nodal point needed to be supported by another supply chain node, i.e., flexibility metrics with three indicators. Also, keeping in view the customer requirements, customer metrics were developed another nodal point for assessing supply chain performance. This nodal point had the support of six performance indicators. The stakeholder metric presented the final nodal point for assessing supply chain performance. This nodal point used four indicators and projects the monetary outcome of the business. Deshpande (2012) derived a theoretical framework and propositions to appraise and understand the linkages between supply chain performance and organizational performance. In culmination, the description for possible findings and implications of the study for managers was considered. The author argued that increased interaction between important constituents of supply chain management would enhance the organization's ability to meet desired goals.

Effective supply chain performance measurement has been identified as a key issue towards efficient supply chain management (Olugu and Wong, 2009). In the manufacturing environment, performance measurement is based on different quantitative and qualitative factors. Some of these factors may have a larger effect on the performance measure than others. Units of measure of the quantitative factors are different such as time, money, percentage, ratio, and counts. It is indeed required to develop SC performance appraisement module as an effective decision tool for the performance measurement, benchmarking of a supply chain in manufacturing environment (Adel El-Baz, 2011).

In this context, present work aims to explore the extent of research in supply chain performance appraisement (evaluating overall performance index and performance benchmarking) using grey theory as well as grey-MOORA approach.

## 6.4 Problem Definition

In the competitive global business environment achieving sustainable supply chains is an issue that is still to be solved despite of its relevance. Consequently, there are several tools that have emerged in the last years to aid the understanding and support supply chain sustainability. Performance measurement frameworks are helpful tools in facilitating to collect and monitor the evolution of performance of any organizational SC. However, there are few performance measurement frameworks documented in past literature for that purpose lacking of a solid structure that assists to define and implement performance measurement elements in a way that provide an overall evaluation of the sustainability status of the supply chain (Verdecho et al., 2012). This work introduces a novel performance measurement module to fill this research gap.

The supply chain performance measurement using fuzzy logic operation was identified as a new direction in measuring the uncertainty and vagueness surrounding supply chain performance measurement. Direction for further studies in the application of fuzzy logic operation in supply chain management and its performance measurement were also identified in literature (Olugu and Wong, 2009). Apart from fuzzy logic, grey theory has the equivalent potential and can efficiently be utilized in supply chain performance measurement, benchmarking and associated decision-making. Similar to fuzzy numbers in fuzzy set theory, grey numbers possess the capability in efficiently dealing with vague, incomplete linguistic human judgment. In view of that the proposed decision-support systems have been framed to operate under grey environment.

The study has been carried out in two phases.

1. In the first phase, four candidate enterprises (alternatives) have been selected. It has been assumed that they possess similar supply chain hierarchy. A unique decision-making team has been assumed to provide necessary information after visiting individual enterprises. In this part of work, overall supply chain performance index has been computed in relation to individual alternatives. Ill-performing areas have been identified for individual enterprises

separately; and finally, enterprises have been ranked based on their overall supply chain performance index.

2. In the second phase of this work, grey-MOORA technique has been recommended to derive appropriate ranking order (benchmarking) of supply chain performance in relation to candidate alternatives. Traditional MOORA (Multi-Objective Optimization by Ratio Analysis) has been embedded with grey theory to facilitate SC performance appraisement.

## 6.5 Grey Theory

The Grey systems theory is an effective methodology that can be used to solve uncertain problems with partially known information. The basic concept of grey system theory is that all information can be classified into three categories that are labeled with corresponding colors: known information is white, unknown information is black, and the uncertain information is grey (Fig. 6.1).

The following definitions are the basic related to Grey systems theory, taken from Deng (1985, 1989, 1992), Liu et al. (1999) and Liu and Lin (1998, 2006).

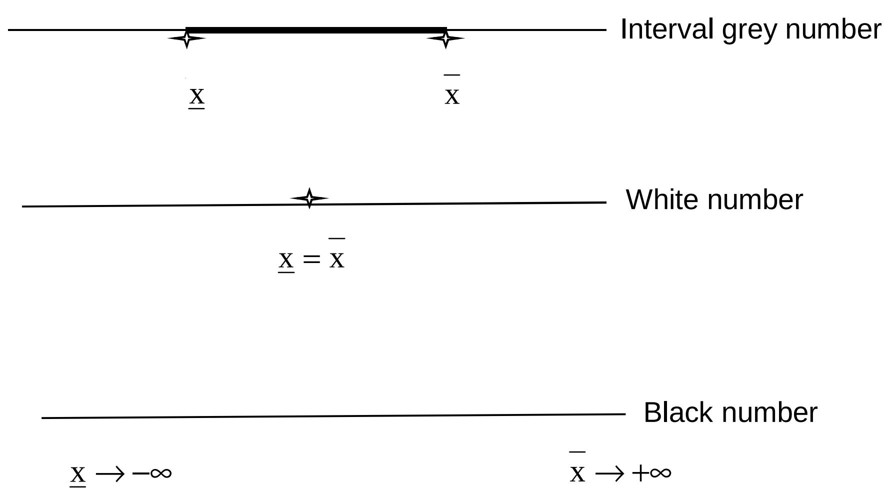



Fig. 6.1: Interval grey, white and black numbers

A grey number, denoted as $\otimes x$, is such a number whose exact value is unknown, but a range within which the value lies is known. There are several types of grey numbers such as: grey numbers with only upper limits, grey numbers with only lower limits, black and white numbers and so on, but we will focus below on interval grey numbers.

A grey number with known upper $\overline{x}$, and lower $\underline{x}$, bounds but unknown distribution information for *x* is called interval grey number (Deng 1989):

$$\otimes x = [\underline{x}, \overline{x}] = [x' \in x \mid \underline{x} \le x' \le \overline{x}] \qquad (6.1)$$

The degree of greyness of an interval number is determined by distance between its bounds. When upper and lower bounds are equal, $\underline{x} = \overline{x}$, interval grey number becomes a white number, i.e. deterministic number. Otherwise, when distance between bounds increases and bounds tend to infinity, $\underline{x} \to -\infty$ and $\overline{x} \to +\infty$, interval grey number becomes a black number.

## 6.5.1 Basic Operations of Interval Numbers

Let $\otimes x_1 = [\underline{x}_1, \overline{x}_1]$ and $\otimes x_2 = [\underline{x}_2, \overline{x}_2]$ be two interval grey numbers. The basic operations of grey numbers $\otimes x_1$ and $\otimes x_2$ are defined as follows (Deng 1992; Liu, Lin 2006):

$$\otimes x_1 + \otimes x_2 = [\underline{x}_1 + \underline{x}_2, \overline{x}_1 + \overline{x}_2] \qquad (6.2)$$

$$\otimes x_1 - \otimes x_2 = [\underline{x}_1 - \overline{x}_2, \overline{x}_1 - \underline{x}_2] \qquad (6.3)$$

$$\otimes x_1 \times \otimes x_2 = \min(\underline{x}_1\underline{x}_2, \underline{x}_1\overline{x}_2, \overline{x}_1\underline{x}_2, \overline{x}_1\overline{x}_2), \max(\underline{x}_1\underline{x}_2, \underline{x}_1\overline{x}_2, \overline{x}_1\underline{x}_2, \overline{x}_1\overline{x}_2) \qquad (6.4)$$

$$\otimes x_1 \div \otimes x_2 = [\underline{x}_1, \overline{x}_2] \times \left[\frac{1}{\underline{x}_2}, \frac{1}{\overline{x}_2}\right] \qquad (6.5)$$

## 6.5.2 Whitened Value

The whitened value of an interval grey number ,$\otimes x$, is a deterministic number with its value lying between the upper and lower bounds of interval $\otimes x$. For a given interval grey number $\otimes x = [\underline{x}, \overline{x}]$ the whitened value $x_{(\lambda)}$ can be determined as follows (Liu, Lin 2006):

$$x_{(\lambda)} = \lambda \underline{x} + (1 - \lambda)\overline{x} \qquad (6.6)$$

Here $\lambda$ as whitening coefficient and $\lambda \in [0,1]$. Because of its similarity with a popular $\lambda$ function formula (6.6) is often shown in the following form:

$$x_{(\lambda)} = (1-\lambda)\underline{x} + \lambda\overline{x} \tag{6.7}$$

For $\lambda$=0.5, formula (6.7) gets the following form:

$$x_{(\lambda=0.5)} = \frac{1}{2}(\underline{x} + \overline{x}) \tag{6.8}$$

### 6.5.3 Signed Distance

Let $\otimes x_1 = [\underline{x}_1, \overline{x}_1]$ and $\otimes x_2 = [\underline{x}_2, \overline{x}_2]$ be two positive interval grey numbers. Then, the distance between $\otimes x_1$ and $\otimes x_2$ can be calculated as signed difference between its centers (Eberly 2007), as is shown below:

$$d(\otimes x_1, \otimes x_2) = \frac{\underline{x}_1 + \overline{x}_1}{2} - \frac{\underline{x}_2 + \overline{x}_2}{2} = \frac{1}{2}[(\underline{x}_1 - \underline{x}_2) + (\overline{x}_1 - \underline{x}_2)] \tag{6.9}$$

### 6.5.4 The Length of Grey Number $\otimes x$

The length of grey number $\otimes x$ is defined as: $L(\otimes x) = [\overline{x} - \underline{x}]$

### 6.5.5 Grey Possibility to compare ranking Order of Grey Numbers

For two grey numbers $\otimes x_1 = [\underline{x}_1, \overline{x}_1]$ and $\otimes x_2 = [\underline{x}_2, \overline{x}_2]$ the possibility degree of $\otimes x_1 \le \otimes x_2$ can be expressed as:

$$P\{\otimes x_1 \le \otimes x_2\} = \frac{\max(0, L^* - \max(0, \overline{x} - \underline{x}))}{L^*} \tag{6.10}$$

Here $L^* = L(\otimes x_1) + L(\otimes x_2)$.

For the position relationship between $\otimes x_1$ and $\otimes x_2$, there exist four possible case on the real number axis. The relationship between $\otimes x_1$ and $\otimes x_2$ is determined as follow, Shi et al. (2005):

**i.** If $\underline{x}_1 = \underline{x}_2$ and $\overline{x}_1 = \overline{x}_2$, we say that $\otimes x_1$ and $\otimes x_2$, denote as $\otimes x_1 = \otimes x_2$. Then $P\{\otimes x_1 \leq \otimes x_2\} = 0.5$

**ii.** If $\underline{x}_2 > \overline{x}_1$, we say that $\otimes x_2$ is larger than $\otimes x_1$, denoted as $\otimes x_2 > \otimes x_1$. Then $P\{\otimes x_1 \leq \otimes x_2\} = 1$

**iii.** If $\overline{x}_2 < \underline{x}_1$, we say that $\otimes x_2$ is smaller than $\otimes x_1$ denoted as $\otimes x_2 < \otimes x_1$. Then $P\{\otimes x_1 \leq \otimes x_2\} = 0$

**iv.** If there is an intercrossing part in them, when $P\{\otimes x_1 \leq \otimes x_2\} > 0.5$, we say that $\otimes x_2$ is larger than $\otimes x_1$, denoted as $\otimes x_2 > \otimes x_1$. when $P\{\otimes x_1 \leq \otimes x_2\} < 0.5$, we say that $\otimes x_2$ is smaller than $\otimes x_1$, denotes as $\otimes x_2 < \otimes x_1$.

## 6.6 The MOORA Method

Multi-Objective Optimization by Ratio Analysis (MOORA) method is introduced by Brauers and Zavadskas (2006) on the basis of previous researches (Brauers 2004a, 2004b).

The method starts with a matrix of responses of different alternatives on different objectives:

$$X = [x_{ij}]_{m \times n} \tag{6.11}$$

Here $x_{ij}$ as the response of alternative *j* on objective or attribute *i*; *i* = 1, 2, …, *n* as the objectives or the attributes; and *j* = 1, 2, ..., *m* as the alternatives.

The MOORA method consists of two parts: the Ratio system and the Reference point approach (Brauers, Zavadskas 2009).

### 6.6.1 The Ratio System Approach of the MOORA Method

Brauers and Zavadskas (2006) proved that the most robust choice for denominator is the square root of the sum of squares of each alternative per objective, and therefore the use of vector normalization method is recommended in order to normalize responses of alternatives. As a result, the following formula proposed by Van Delft and Nijkamp (1977) is used:

$$x_{ij}^{*} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} x_{ij}^{2}}},$$ (6.12)

Here $x_{ij}$ as response of alternative *j* on objective *i*; *j* = 1,2, ..., *m*; *m* the number of alternatives; *i* = 1,2, … *n*; *n* the number of objectives; $x_{ij}^{*}$ as normalized response of alternative *j* on objective *i*; and $x_{ij}^{*} \in [0,1]$

For optimization based on the Ratio system approach of MOORA method, normalized responses are added in case of maximization and subtracted in case of minimization, which can be expressed by the following formula:

$$y_{j}^{*} = \sum_{i=1}^{g} x_{ij}^{*} - \sum_{i=g+1}^{i=n} x_{ij}^{*},$$ (6.13)

$x_{ij}^{*}$ as normalized response of alternative *j* on objective *i*; *i* = 1, 2, ..., *g* as the objectives to be maximized; *i* = *g* + 1, *g* + 2, ..., *n* as the objectives to be minimized; *j* = 1, 2, ..., *m* as the alternatives; and $y_{j}^{*}$ as the overall ranking index of alternative *j*, $y_{j}^{*} \in [-1,1]$

After that, the optimal alternative based on the ratio system part $A_{RS}^{*}$ can be determined using the following formula:

$$A_{RS}^{*} = \{a_{j} \mid = \max_{j}\ y_{i}^{*}\}$$ (6.14)

## 6.6.2 The Reference Point Approach of the MOORA Method

The Reference point approach of the MOORA method is based on the Ratio system and starts from already normalized responses of alternatives, obtained by Eq. (6.12). After considering the most important reference point metrics, Brauers and Zavadskas (2006, 2009), Brauers et al. (2008a) and Brauers (2008) emphasize that the min-max metric is the best choice among all of them. Therefore, for optimization based on the reference point approach Brauers and Zavadskas (2006) proposed the following formula:

$$\max_{j}\left\{\max_{i} \mid r_{i}^{*} - x_{ij}^{*} \mid\right\}$$ (6.15)

Here $r_{i}$ as *i*-th coordinate of the reference point; $x_{ij}^{*}$ as the normalized response of alternative *j* on objective *i*; *i* = 1, 2, ..., *n* as the objectives; and *j* = 1, 2, ..., *m* as the alternatives.

For further simpler presentations, we will mark distance from an alternative to the reference point with *d* and therefore, Eq. (6.15) gets the following form:

$$\min_{j} \max_{i} d_{ij} , \tag{6.16}$$

$$d_{ij} = | r_i^* - x_{ij}^* | \tag{6.17}$$

$$r_i = \begin{cases} \max\limits_{j} x_{ij}^* & \text{for objectives to be maximized} \\ \min\limits_{j} x_{ij}^* & \text{for objectives to be minimized} \end{cases} \tag{6.18}$$

Here $x_{ij}^*$ as the normalized response of alternative *j* on objective *i*; $r_i$ as *i*ih coordinate of the reference point; $d_{ij}$ as unsigned distance of alternative *j* to the *i*th coordinate of reference point; *i* = 1, 2,.... *n* as the objectives; and *j* = 1, 2, ..., *m* as the alternatives.

Based on the Reference point approach of the MOORA method, the optimal alternative $A_{RP}^*$ can be determined using the following formula:

$$A_{RP}^* = \{a_j \mid = \min_{j} \max_{i} d_{ij}\} \tag{6.19}$$

## 6.6.3 The Importance Given to Objectives

When solving real-world problems using MCDM methods, objectives do not always have the same importance, i.e. some objectives are more important than the others. In order to give more importance to an objective, it could be multiplied with a Significance Coefficient (Brauers, Zavadskas 2009). Importance given to objectives has influence on Ratio system and Reference point approach of the MOORA method.

In the Ratio system approach importance given to objectives is included by modifying the Eq. (6.13) which gets the following form:

$$\ddot{y}_j^* = \sum_{i=1}^{g} s_i x_{ij}^* - \sum_{i=g+1}^{i=n} s_i x_{ij}^* , \tag{6.20}$$

Here $s_i$ as significance coefficient of objective *i*; *i* = 1, 2, ..., *g* as the objectives to be maximized; *i* = *g*+1, *g*+2, ..., *n* as the objectives to be minimized; *j* = 1, 2, ..., *m* as the alternatives; and $\ddot{y}_j^*$

as the overall ranking index of alternative *j* with respect to all objectives with significance coefficients, $\ddot{y}_j^* \in [-1,1]$.

After that, the Eq. (6.14) still remains to determine the most appropriate alternative based on Ratio system approach of the MOORA method.

As the most effective way to include importance given to objectives into Reference point approach of the MOORA method, we propose to adopt Eq. (6.17), which after adoption gets the following form:

$$d_{ij} = s_i \,|\, r_i^* - x_{ij}^* \,|, \tag{6.21}$$

Here $s_i$ as significance coefficient of objective *i*; $x_{ij}^*$ as the normalized response of alternative *j* on objective *i*; $r_i$ as $i^{th}$ coordinate of the reference point; $d_{ij}$ as distance of alternative *j* to the $i^{th}$ coordinate of reference point; *i* = 1, 2, ..., *n* as the objectives; and *j* = 1, 2, ..., *m* as the alternatives.

After that, the Eq. (6.19) still remains without changes for determining the most appropriate alternative based on the Reference point approach of the MOORA method.

## 6.7 The Grey-MOORA

The MOORA method is simple and robust compared to the other MADM methods, such as TOPSIS, VIKOR and GRA (İç and Yıldırım, 2013). Owing to the advantages of MOORA method over existing MCDM methods, the study has aimed to develop a decision support module by combing grey theory and MOORA. Grey numbers set theory and grey mathematics have been integrated with MOORA to deal with subjective evaluation information effectively towards ranking of alternatives and selection of the best one. The Ratio System is as follows:

The ranking scores are determined by MOORA index $(Y_i^*)$. The MOORA index is calculated using the following equation. For, multi-criteria situation, weighted normalized values are added in case of maximization (for benefit response) and subtracted in case of minimization (for cost response).

$$Y_i^* = \sum_{j=1}^{t} Y_{ij} - \sum_{j=t+1}^{r} Y_{ij}$$

Here $t$ is the number of responses to be maximized, $(r-t)$ is the number of responses to be minimized and $(Y_i^*)$ is the ranking score of $i^{th}$ scenario with respect to all of the responses. A larger $(Y_i^*)$ value produces better multi-response performance.

The procedure of selecting the most appropriate alternative using the MOORA method involves several important stages that should be considered before an extension of the MOORA method with interval grey numbers, and these are:

**Stage 1:** Transforming responses of alternatives into dimensionless values;
**Stage 2:** Determining overall ranking indexes for considered alternatives based on Ratio System part of MOORA method; and
**Stage 3:** Determining distances between considered alternatives and reference point based of the reference point part of MOORA method.

**Stage 1: Transformation into dimensionless values**

The first step that should be considered is a way of transforming responses of alternatives into dimensionless values. Compared with other normalization methods, vector normalization method is the most complex. Therefore, in some proposed extensions of other MCDM methods, vector normalization is often replaced by a simpler, usually with a linear transformation - max method (Wang, Elhag 2006). However, this approach does not represent generally adopted rule. For the normalization of responses of alternatives expressed in the form of interval numbers, Jahanshahloo et al. (2006) suggested the use of the following formula:

$$\otimes x_{ij}^{*} = \frac{\otimes x_{ij}}{\sqrt{\sum_{j=1}^{m} \underline{x}_{ij}^{2} + \overline{x}_{ij}^{2}}} \quad (6.22)$$

Eq. (6.22) provides the appropriate form for normalizing responses of alternatives expressed by interval grey numbers. However, in cases of multi-criteria optimizations which require simultaneously the use of crisp and interval grey numbers, the previously mentioned formula give unsatisfactory results. Therefore, we suggest the use of the following formula:

$$\otimes x_{ij}^{*} = \frac{\otimes x_{ij}}{\sqrt{\frac{1}{2}\sum_{j=1}^{m} \underline{x}_{ij}^{2} + \overline{x}_{ij}^{2}}} \quad (6.23)$$

Based on the Eq. (6.23), upper and lower bounds of an interval grey number can be determined using the following formulae:

$$\overline{x}_{ij}^{*} = \frac{\overline{x}_{ij}}{\sqrt{\frac{1}{2}\sum_{j=1}^{m} \underline{x}_{ij}^{2} + \overline{x}_{ij}^{2}}} \quad \text{and} \tag{6.24}$$

$$\underline{x}_{ij}^{*} = \frac{\underline{x}_{ij}}{\sqrt{\frac{1}{2}\sum_{j=1}^{m} \underline{x}_{ij}^{2} + \overline{x}_{ij}^{2}}}. \tag{6.25}$$

**Stage 2: Determining overall ranking index based on Ratio system approach of the MOORA method**

For optimization based on the Ratio system part of the MOORA method we start from the formula:

$$y_j^{*} = y_j^{+} - y_j^{-}, \tag{6.26}$$

$$y_j^{+} = \sum_{i \in \Phi_C^{+}} s_i x_{ij}^{*} + \sum_{i \in \Phi_G^{+}} \otimes s_i x_{ij}^{*} \tag{6.27}$$

$$y_j^{-} = \sum_{i \in \Phi_C^{-}} s_i x_{ij}^{*} + \sum_{i \in \Phi_G^{-}} \otimes s_i x_{ij}^{*} \tag{6.28}$$

Here $y_j^{*}$ as the overall ranking index of alternative *j*; $y_j^{+}$ and $y_j^{-}$ as total sums of maximizing and minimizing responses of alternative *j* to objectives respectively; a $s_i$ s significance coefficient of objective *i*; $x_{ij}^{*}$ and $\otimes x_{ij}^{*}$ as the normalized responses of alternative *j* on different objectives, which are expressed in the form on crisp or interval grey numbers; $\Phi_C^{+}$ and $\Phi_G^{+}$ as , sets of objectives to be maximized expressed in the form on crisp or interval grey numbers; $\Phi_C^{-}$ and $\Phi_G^{-}$ are sets of objectives to be minimized expressed in the form on crisp or interval grey numbers. By replacing Eq. (6.27) and Eq. (6.28) in the Eq. (6.26), we get the following formula:

$$y_j^{+} = \sum_{i \in \Phi_C^{+}} s_i x_{ij}^{*} - \sum_{i \in \Phi_C^{-}} s_i x_{ij}^{*} + \sum_{i \in \Phi_G^{+}} \otimes s_i x_{ij}^{*} - \sum_{i \in \Phi_G^{-}} \otimes s_i x_{ij} \tag{6.29}$$

Based on Eqs. (6.29, 6.7 and 6.9) we get the final and complete formula form:

$$y_j^{+} = \sum_{i\in\Phi_C^{+}} s_i x_{ij}^{*} - \sum_{i\in\Phi_C^{-}} s_i x_{ij}^{*} + (1-\lambda)\left(\sum_{i\in\Phi_G^{+}} s_i \underline{x}_{ij}^{*} - \sum_{i\in\Phi_G^{-}} s_i \underline{x}_{ij}^{*}\right) + \lambda\left(\sum_{i\in\Phi_G^{+}} s_i \overline{x}_{ij}^{*} - \sum_{i\in\Phi_G^{-}} s_i \overline{x}_{ij}^{*}\right) \tag{6.30}$$

with: $s_i$ significance coefficient of objective *i*; $x_{ij}^{*}$ as the normalized responses of alternative *j* on objective *i* and $i\in\Phi_C$; $\underline{x}_{ij}^{*}$ and $\overline{x}_{ij}^{*}$ as the normalized bounds of interval grey number which represents response of alternative *j* on objective *i* and $i\in\Phi_G$, respectively; $\Phi_C$ and $\Phi_G$ assets of objectives expressed in the form of crisp or interval grey numbers, respectively; $\lambda$ as the whitening coefficient; $y_j^{*}$ as the overall ranking index of alternative *j*; $\Phi_C^{+}$ and $\Phi_G^{+}$ as, sets of objectives to be maximized expressed in the form on crisp or interval grey numbers; $\Phi_C^{-}$ and $\Phi_G^{-}$ are sets of objectives to be minimized expressed in the form on crisp or interval grey numbers; *i* = 1,2, … *n* as the objectives; and *j* = 1,2, ..., *m* as the alternatives.

The proposed Eq. (6.30) is quite complex but it enables selection of more appropriate alternative, i.e. optimization, in the cases of solving many complex real-world problems such as:

– Decision making problems where responses of alternatives can be more appropriately expressed by simultaneous use of crisp and interval grey numbers;

– Decision making problems where responses of alternatives can be more appropriately expressed with interval grey numbers, such as problems that require certain estimates and predictions; and

– Problems that require investigation of more options in order to choose the most appropriate alternative i.e. check variants resulting from the optimistic, realistic and pessimistic attitude of decision makers.

In the case of solving complex real-world problems that require simultaneous use of crisp and interval grey numbers, Eq. (6.30) provides adequate ability to rank and select the most appropriate alternative.

In the case of solving well-structured problems, the second part of Eq. (6.30) which includes the impact of objectives whose responses are expressed using interval grey numbers, has no influence on ranking index and therefore, Eq. (6.30) can be transformed into following forms:

$$y_j^* = \sum_{i \in \Phi_C^+} x_{ij}^* - \sum_{i \in \Phi_C^-} x_{ij}^*; \text{or} \tag{6.31}$$

$$y_j^+ = \sum_{i \in \Phi_C^+} s_i x_{ij}^* - \sum_{i \in \Phi_C^-} s_i x_{ij}^*, \tag{6.32}$$

These are for the case, when objectives have different significances. The Eq. (6.31) and Eq. (6.32) have the same meanings as Eq. (6.13) and Eq. (6.20), respectively, in original MOORA method. On the other hand, in the case of solving semi-structured problems, the first part of Eq. (6.30) which represents the impact of objectives whose responses are expressed using crisp numbers, has no influence to the overall ranking index and therefore it can be transformed into one of three following forms:

**i.** When objectives have the same significance:

$$y_j^* = (1-\lambda)\left(\sum_{i \in \Phi_G^+} \underline{x}_{ij}^* - \sum_{i \in \Phi_G^-} \underline{x}_{ij}^*\right) + \lambda\left(\sum_{i \in \Phi_G^+} \overline{x}_{ij}^* - \sum_{i \in \Phi_G^-} \overline{x}_{ij}^*\right); \tag{6.33}$$

**ii.** When the decision maker has no preferences $(\lambda = 0.5)$ :

$$y_j^* = \frac{1}{2}\left(\sum_{i \in \Phi_G^+} s_i \underline{x}_{ij}^* - \sum_{i \in \Phi_G^-} s_i \underline{x}_{ij}^*\right) + \frac{1}{2}\left(\sum_{i \in \Phi_G^+} s_i \overline{x}_{ij}^* - \sum_{i \in \Phi_G^-} s_i \overline{x}_{ij}^*\right); \tag{6.34}$$

**iii.** And when the decision maker has no preference and objectives have the same significance:

$$y_j^* = \frac{1}{2}\left(\sum_{i \in \Phi_G^+} \underline{x}_{ij}^* - \sum_{i \in \Phi_G^-} \underline{x}_{ij}^*\right) + \frac{1}{2}\left(\sum_{i \in \Phi_G^+} \overline{x}_{ij}^* - \sum_{i \in \Phi_G^-} \overline{x}_{ij}^*\right). \tag{6.35}$$

During problem solution, i.e. ranking of alternatives, the attitude of the decision makers can lie between pessimistic and optimistic, and the whitening coefficient $\lambda$, allows expression of decision makers degree of optimism or pessimism.

In the cases of particularly expressed optimism, the whitening coefficient $\lambda$, in accordance with the Eq. (6.7), takes higher values $(\lambda \to 1)$ and ranking order of alternatives is mainly based on the upper bounds of intervals with which overall response of each alternative is expressed, $y_{j(\lambda=1)} = \overline{y}_j^*$. On the other hand, in the cases of particularly expressed pessimism, the whitening coefficient $\lambda$ takes lower values $(\lambda \to 0)$ and ranking order of alternatives is mainly based on lower bounds of the intervals, $y_{j(\lambda=0)} = \overline{y}_j^{\,*}$.

**Stage 3: Determining overall ranking index based on Reference point approach of the MOORA method**

The most appropriate alternative based on the Reference point approach of the MOORA method when ratings of alternatives are expressed using exact values can be obtained by the Eq. (6.16). However, this formula should be adopted in cases when the Reference point approach of the MOORA method is used to solve complex real-world problems. To explain our approach in details, we start from the min-max metric expressed by the formula:

$$\min_{j} \max_{i} d_{ij} \tag{6.36}$$

with: $d_{ij}$ as distance of alternative *j* to the *i*th coordinate of reference point. In the course of solving many complex real-world problems, responses to the objectives are simultaneously expressed using crisp and interval grey numbers. In this case, the reference point cannot be expressed adequately with “simple” point in *n*-dimensional space. We believe that the reference grey point is a more appropriate solution, where coordinates of grey reference point may be crisp or interval grey numbers, depending on type of values which is used to express ratings of alternatives to the corresponding objectives. Therefore, for determining $d_{ij}$ and $r_i$ for objective *i* in different cases, we propose the following:

**i.** For objective *i* with crisp responses, the correspondent coordinate of the reference grey point is calculated using the Eq. (6.18) and distance to the reference point using Eq. (6.17) or Eq. (6.21) when objectives have different significances.

**ii.** For objectives whose responses are expressed using interval grey numbers formulae are more complex, especially when decision makers have opportunity to express their attitudes about optimism or pessimism. For these reasons, we start from the following formulae:

$$d_{ij} = (1-\lambda)\underline{d}_{ij} + \lambda\overline{d}_{ij}; \text{or} \tag{6.37}$$

$$d_{ij} = s_i \left\langle (1-\lambda)\underline{d}_{ij} + \lambda\overline{d}_{ij} \right\rangle, \tag{6.38}$$

when, objectives have different significances, where:

$$\underline{d}_{ij} = |\, \underline{r}_i - \underline{x}_{ij}^{*} \,|; \text{and} \tag{6.39}$$

$$\bar{d}_{ij} = |\,\bar{r}_i - \bar{x}_{ij}^*\,|, \tag{6.40}$$

with: $\lambda$ as whitening coefficient; $\underline{d}_{ij}$ and $\bar{d}_{ij}$ as distances of alternative *j* to the *i*-th coordinate of reference grey point; $s_i$ as significance coefficient of objective *i*; *i* = 1, 2, ..., *n* as the objectives; and *j* = 1, 2, ..., *m* as the alternatives.

In the proposed approach every coordinate of reference grey point is represented by appropriate interval grey numbers which bounds are determined by using the following formulae:

$$\left.\begin{aligned} \bar{r}_i &= \max_j x_{ij}^* \\ \underline{r}_i &= \min_j x_{ij}^* \end{aligned}\right\rangle \text{for objectives to be maximised; and} \tag{6.41}$$

$$\left.\begin{aligned} \bar{r}_i &= \min_j x_{ij}^* \\ \underline{r}_i &= \max_j x_{ij}^* \end{aligned}\right\rangle \text{for objectives to be minimised,} \tag{6.42}$$

Depending on decision makers' preferences, i.e. whitening coefficient value, the Eq. (6.37) and Eq. (6.38) may have the following specific forms:

**i.** in the case of extremely pessimistic decision maker attitude, $(\lambda = 0)$:

$$d_{ij(\lambda=\mathbf{0})} = \left\langle \begin{array}{ll} \underline{d}_{ij} & \text{when objective have the same significance; or} \\ s_i \underline{d}_{ij} & \text{when objective have diffenent siginificance.} \end{array}\right. \tag{6.43}$$

**ii.** in the case of moderate optimism or when the decision maker has no preference, $(\lambda = 0.5)$:

$$d_{ij(\lambda=\mathbf{0.5})} = \left\langle \begin{array}{ll} (\underline{d}_{ij} + \bar{d}_{ij})/2 & \text{when objective have the same significance; or} \\ s_i(\underline{d}_{ij} + \bar{d}_{ij})/2 & \text{when objective have diffenent siginificance.} \end{array}\right. \tag{6.44}$$

**iii.** and finally in the case of extremely optimistic decision maker attitude, $(\lambda = 1)$:

$$d_{ij(\lambda=\mathbf{1})} = \left\langle \begin{array}{ll} \bar{d}_{ij} & \text{when objective have the same significance; or} \\ s_i \bar{d}_{ij} & \text{when objective have diffenent siginificance.} \end{array}\right. \tag{6.45}$$

## 6.8 Proposed Appraisement Modeling

The SC performance appraisement platform proposed in this research consists of two phases. 1. Exploration of grey mathematics and 2. Exploration of grey-MOORA towards facilitating such decision-modeling

### 6.8.1 Performance Appraisement and Benchmarking by Grey Theory

The evaluation index of supply chain performance platform adapted in this work has been shown in Table 6.1. The definitions of various SC performance indices (as indicated in Table 6.1) have been furnished in the Appendix E (at the end of the dissertation).

The two-level hierarchical model consists of 1st level indices as well as 2nd level indices. Customer Service, Purchasing Management, Administration/Financial Management, Process, Cross Functional Measures, Manufacturing Management, Marketing Management, Extended Enterprise Measures and Logistics Performance have been considered at the first level followed by second level which encompasses a number of supply chain attributes. An approach based on grey numbers as well as grey possibility degree has been explored here to evaluate an overall performance index of alternative SCs; and also to identify ill-performing areas of the SC network.

Assume that $Q=\{Q_1,Q_2,Q_3,...Q_n\}$ is a set of n attributes representative of SC performance extent. The attributes are additively independent. $\otimes w=\{\otimes w_2,\otimes w_2,\otimes w_2....\otimes w_n\}$ is the vector of attribute weights. In this work, the attribute weights and corresponding appropriateness ratings (performance estimates) of individual alternative are considered as linguistic variables. Here, these linguistic variables corresponding to weight assignment can be expressed in grey numbers by 1-7 scale as shown in Table 6.2.1. The attribute ratings $\otimes x$ can be also expressed in grey numbers by 1-7 scale shown in Table 6.2.2. The procedural steps are summarized as follows.

**Step 1:** Form a committee of decision-makers (DMs).

**Step 2:** Finalization of linguistic scale for assignment of attribute weight as well as appropriateness rating.

**Step 3:** Collection of DMs linguistic information.

**Step 4:** Transformation of linguistic information into appropriate grey numbers.

**Step 5:** Computation of aggregated weight as well as aggregated rating against SC performance attributes.

Assume that a decision-making group has 'K' members; then the attribute weight of attribute $Q_j$ can be calculated as:

$$\otimes w_j = \frac{1}{K}\left\{\otimes w_j^{\,1}, \otimes w_j^{\,2}, \otimes w_j^{\,3} \ldots \otimes w_j^{\,k}\right\}, \tag{6.46}$$

Here $\otimes w_j^{\,k}\,(j = 1, 2, 3, \ldots n)$ is the attribute weight of $K^{th}$ DM and can be described by grey number $\otimes w_j^{\,k} = [\underline{w}_j^{\,k}, \overline{w}_j^{\,k}]$.

In order to determine attribute rating value (aggregated value), we use:

$$\otimes X_{ij} = \frac{1}{K}\left\{\otimes X_{Ij}^{\,1}, \otimes X_{ij}^{\,2}, \otimes X_{ij}^{\,3} \ldots \otimes X_{ij}^{\,k}\right\} \tag{6.47}$$

Here $\otimes X_{Ij}\,(i = 1, 2, 3, \ldots m; j = 1,2,3 \ldots n)$ is the attribute rating value of $K^{th}$ DM and can be described by grey number $\otimes X_{ij}^{\,k} = [\underline{X}_{ij}^{\,k}, \overline{X}_{ij}^{\,k}]$.

**Step 6:** Estimation of appraisement index is carried out as follows.

GOPI represents the grey overall performance index. The grey index has been calculated at the attribute level ($2^{nd}$ level) and then extended to $1^{st}$ level. Grey index system at first level encompasses several evaluation indices. The grey index of first level index can be calculated as follows:

$$U_i = \frac{\sum_{j=1}^{n} (w_{ij} \otimes U_{ij})}{\sum_{j=1}^{n} (w_{ij})} \tag{6.48}$$

Here $U_{ij}$ represent aggregated performance measure (rating) and $w_{ij}$ represent aggregated grey weight for priority importance corresponding to attributes $C_{ij}$ which is under $i^{th}$ $1^{st}$ level index.

Thus, grey overall performance index $U(GOPI)$ can be obtained as follows:

$$U(GOPI) = \frac{\sum_{j=1}^{n} (w_i \otimes U_i)}{\sum_{j=1}^{n} (w_i)} \tag{6.49}$$

Here $U_i$ is rating of $i^{th}$ first level capability $C_i$ ; $w_i$ is weight of $i^{th}$ first level index and i =1,2,3,…n

**Step 7:** Identification of week areas which need future improvement.

After evaluating GOPI, simultaneously it is also felt indeed necessary to identify and analyze the week areas towards supply chain performance improvement. Grey performance importance index (GPII) may be used to identify these obstacles. GPII combines the performance rating and importance weight of various attributes. The higher the GPII of a factor, the higher is the contribution. The GPII can be calculated as follows in Eq. (6.52) and Eq. (6.11). The concept of GPII is similar to the fuzzy performance importance index (FPII) that was introduced by (Lin et al., 2006) and (Vinodh and Devadasan, 2011) for agility extent measurement in supply chain:

$$GPII_{ij} = (w_{ij}{}' \otimes U_{ij}) \tag{6.50}$$

Here, $w_{ij}{}' = [(1,1) - w_{ij}]$ (6.51)

$w_{ij}$ is the grey importance weight of j$^{th}$ attribute under i$^{th}$ 1$^{st}$ level index. If used directly to calculate the GPII, the importance weights $w_{ij}$ will neutralize the performance ratings in computing GPII; in this case it will become impossible to identify the actual weak areas (low performance rating and high importance). If $w_{ij}$ is high, then the transformation $[(1,1) - w_{ij}]$ is low. Consequently, to elicit a factor with low performance rating and high importance, for each second level attribute ij, ( j$^{th}$ attribute under i$^{th}$ 1$^{st}$ level index), the grey performance importance index $GPII_{ij}$, indicating the effect of each enable-attribute that contributes to GOPI, has been defined as:

$$GPII_{ij} = [(1,1) - w_{ij}] \otimes U_{ij} \tag{6.52}$$

GPII need to be ranked to identify individual attribute's performance level. Based on that poorly performing attributes can be sorted out and in future, the particular alternative should pay attention towards improving those attribute aspects in order to boost up overall supply chain performance extent.

### 6.8.2 Empirical Data Analyses

For evaluating the importance weights of 1$^{st}$ level as well as 2$^{nd}$ level attributes, a committee of five DMs (DM1, DM2, DM3, DM4, DM5) has been assumed constructed to express their subjective preferences (priority importance) in linguistic terms (Tables 6.3- 6.4) which have been further transformed into grey numbers. Similarly, the decision-making group has been assumed instructed to assign appropriateness rating against individual 2nd level performance indices using linguistic evaluation score (Tables 6.5-6.8) for each of four alternatives, respectively.

Using Eq. (6.46) and Eq. (6.47), group decision has been combined to compute aggregated grey performance rating of attributes. Similarly, aggregated grey priority weights have also been computed for 1st level as well as 2nd level attributes (Tables 6.9-6.10). Similarly aggregated grey performance ratings have been computed for individual 2nd level attributes of alternative SCs. Results of computations have been furnished in Table 6.11 (for alternative 1 and 2), Table 6.12 (for alternative 3 and 4). Eq. (6.48) has been used to evaluate computed performance rating of each 1st index corresponding of four alternative SCs. Results of computations have been furnished in Table 6.13 (for alternative 1 and 2), Table 6.14 (for alternative 3 and 4).

Finally, GOPI has been computed using Eq. (6.49). The GOPI thus becomes [2.88, 12.75]; [3.81, 15.94]; [1.58, 7.25]; [3.73, 15.11] for alternative SC 1, 2, 3 and 4 respectively. GOPI can be compared with predefined grey measurement scale set by the management to check the existing supply chain performance level for the said alternative and to seek for week performing areas which need future improvement.

The exploration of grey based decision support system (DSS) towards supply chain performance assessment is indeed new. No supporting literature is available to infer the acceptable range of GOPI. Therefore, in this work an ideal GOPI has been defined and the grey possibility degree between ideal GOPI and the alternative companies GOPI have been computed. The alternative corresponding to the lowest grey possibility degree assumes highest ranking order. Thus, alternative companies have been ranked accordingly (Table 6.19).

GPII has been computed against each of the 2nd level attribute (for alternatives 1, 2, 3 and 4, respectively) and furnished in Tables 6.15-6.18. The concept of 'grey possibility degree' has been explored to identify poorly performing areas of the particular alternatives considered. Grey possibility degree between GPII of individual attributes (at 2nd level) has thus been computed with reference to the 'ideal GPII' value. Lesser value of grey possibility degree corresponds to higher degree of performance. In other words, well performing attributes are said to contribute more to the overall grey performance estimate. By this way, attributes have been ranked accordingly and thus, improvement opportunities have been clearly identified. Ideal GPII thus becomes: [1.85, 4.31]

Alternative SCs have been ranked finally in accordance with their overall performance extent. Using the concept of 'grey possibility degree' with respect to Ideal GOPI [3.81, 15.94], alternative supply chains has been ranked (Table 6.19).

### 6.8.3 Performance Appraisement and Benchmarking by Grey-MOORA: Empirical Analyses

In this part of work, we highlighted application of the MOORA method coupled with interval grey numbers (Grey-MOORA). The selected objectives, significance coefficients, optimization directions and responses considered for the four alternative SCs have been shown in Table 6.20. The response (grey ratings of 1st level indices) values have been obtained from Tables 6.13-6.14. All 1st level indices have been assumed beneficial in nature (higher-is-better) and they correspond to equal priority importance (crisp weight 0.125).

Normalization has been made by using Eq. (6.23), or more precisely: values which represent the upper bounds of interval grey numbers have been normalized using Eq. (6.24); whilst values which represents the lower bounds of interval grey numbers have been normalized using Eq. (6.25). Then normalized decision-making matrix appears as shown in Table 6.21. On the basis of normalized decision-making matrix, we used the Eq. (6.34) in order to generate the ranking results obtained using extended ratio system part of the MOORA method as shown in Table 6.22. Then to verify obtained ranking results, the comparative review of ranking results obtained using 'grey method' (Section 6.8.2) and ranking results obtained by proposed approach (ratio system part of grey-MOORA) has been furnished in Table 6.23. It can be seen from Table 6.22, the ranking order obtained using grey method and extended ratio system approach of the MOORA method appears the same. Ranking results obtained using Eq. (6.30) for different characteristic values of whitening coefficient $\lambda$ have been shown in Table 6.24.

Then we used the extended reference point approach of the MOORA method. Extended reference point approach of the MOORA method starts from normalized responses of alternatives on objectives. Using data shown in Table 6.21 and Eq. (6.41) and Eq. (6.42), we determined coordinates of reference grey point (Table 6.25) showing the distances of any alternative to reference grey point obtained using Eq. (6.39) and Eq. (6.40). Then by the use of Eq. (6.38), we determined resulting distance of the alternative $j$ from the $i^{th}$ coordinate of reference point. The resulting distances of alternative to the reference points for ($\lambda$=0 and 1) have values shown in Table 6.26 and Table 6.27.

Then in the same way by the use of Eq. (6.38), we determined resulting distance of alternative $j$ from the $i^{th}$ coordinate of reference point. For the sake of optimism, the resulting distances of any alternative to the reference point for ($\lambda$=0.5) assume values shown in Table 6.28. The resulting distance with highest value for any alternative and corresponding ranking order has also been shown in Table 6.28.

Ranking results obtained using extended ratio system part of the MOORA method (for different values of $\lambda$) by using Eq. (6.38) have been presented in Table 6.29. The final ranking order has been decided by using Dominance Theory exploring the results obtained from different parts (ratio system and reference point approach) of grey-MOORA (Table 6.30).

## 6.9 Managerial Implications

Supply chain management concept originated from the recognition that the process of transforming raw materials into final products and delivering those products to customers is becoming increasingly complex (Olugu and Wong, 2009). The strategic dimension of supply chains makes it paramount that their performances are measured (Estampe et al., 2010). The practice of SC performance assessment is very helpful in monitoring ongoing performance status of different key elements of the SC and to compare the existing performance level with respect to the desired one. SC performance appraisement additionally provides a snap-shot of the existing SC performance scenario and consequently helps in identifying ill-performing areas within a SC. Moreover, different enterprises (operating under similar SC) can be compared with respect to overall performance extent (performance benchmarking). By this way best practices of the efficient organizations (peers) can easily be identified and transferred to different organizations. However, it is the management task to select the group of decision-makers participating in the SC performance appraisement assignment. The linguistic scale (and corresponding grey numbers representations) must be predefined and approved by the top managerial level. Enterprise benchmarking (with respect to SC overall performance degree) can only be possible provided candidate alternative enterprises (their SCs) possess similar SC hierarchy.

## 6.10 Concluding Remarks

Supply chain management has received considerable attention in the past business management literature. Supply chain can be viewed as a continuous process, from raw materials to finished goods. It contains different functions such as products design, forecasting, purchasing, process design, manufacturing, distribution, sales and marketing. Improvement of this business integration enables management to focus upon managing the business and delegating the management of the support infrastructure to achieve the benefits of the economies of scale. Success in the flow of supply chain management produces products of high quality at low cost and a good customer service (Adel El-Baz, 2011). Supply chain performance appraisement is a utmost important issue for the success of supply chain management. Supply chain may differ in its structure from one enterprise to another, and consequently, performance indicators (measures, metrics or indices) may differ accordingly. Most of the SC performances indices being qualitative; one has to analyze subjective judgment of the decision-making team. Therefore, a strong logical mathematic base appraisement framework is indeed necessary. In this context, the present work exhibits grey based decision support system for SC performance appraisement. The objectives are of threefold. Firstly, it is aimed to estimate overall performance extent; secondly, to identify ill-performing areas; and finally, to benchmarking alternative industries SCs in relation of their performance level. In first part of the work, a framework has been developed exploring simple grey mathematics to quantify overall SC performance extent. This work has been further extended to identify ill-performing areas which require future improvement and to benchmark alternative SCs. Aforesaid module explores grey weight as well as grey rating with respect to individual performance indices. In contrast to that grey-MOORA (adapted in the later part of the work) assumes crisp weight of the indices. Grey-MOORA cannot provide unique SCs overall performance estimate but it is helpful in accurate estimating of performance ranking order of alternative SCs (Dominance Theory). Furthermore, grey-MOORA method operates on a single set of criteria level ($1^{st}$ level indices). If SC structure is of multi-level, by using grey mathematics we have to reduce it into $1^{st}$ level; then grey-MOORA can be applied.

Empirical case study reflects in-depth understanding of aforesaid approaches. Real case study may be performed in future to improve the said appraisement platform.

Table 6.1: Evaluation Index System of Supply Chain Performance

| Goal | 1st level indices | 2nd level indices |
|---|---|---|
| Evaluation Index of Supply Chain Performance, C | Customer Service, $C_1$ | Order Fill Rate, $C_{11}$ |
| | | Line Item Fill Rate, $C_{12}$ |
| | | Quantity Fill Rate, $C_{13}$ |
| | | Backorders/Stock outs, $C_{14}$ |
| | | Customer Satisfaction, $C_{15}$ |
| | | %Resolution of first customer call, $C_{16}$ |
| | | Customer Returns, $C_{17}$ |
| | | Order Track and Trace Performance, $C_{18}$ |
| | | Customer Disputes, $C_{19}$ |
| | | Order Entry Accuracy, $C_{1,10}$ |
| | | Order Entry Times, $C_{1,11}$ |
| | Purchasing Management, $C_2$ | Material Inventories, $C_{21}$ |
| | | Supplier Delivery Performance, $C_{22}$ |
| | | Material/Component Quality, $C_{23}$ |
| | | Material Stock Outs, $C_{24}$ |
| | | Unit Purchase Costs, $C_{25}$ |
| | | Material Acquisition Costs, $C_{26}$ |
| | | Expediting Activities, $C_{27}$ |
| | Administration/Financial Management, $C_3$ | Cash Flow, $C_{31}$ |
| | | Revenue, $C_{32}$ |
| | | Return on Capital Employed, $C_{33}$ |
| | | Cash-to-Cash Cycle, $C_{34}$ |
| | | Return on Investment, $C_{35}$ |
| | | Revenue Per Employee, $C_{36}$ |
| | | Invoice Errors, $C_{37}$ |
| | | Return on Assets, $C_{38}$ |
| | Process, Cross Functional Measures, $C_4$ | Forecast Accuracy, $C_{41}$ |
| | | Percent Perfect Orders, $C_{42}$ |
| | | New Product-Time-To-Market, $C_{43}$ |
| | | New Product-Time-To-First-Make, $C_{44}$ |
| | | Planning Process Cycle Time, $C_{45}$ |
| | | Schedule Changes, $C_{46}$ |
| | Manufacturing Management, $C_5$ | Product Quality, $C_{51}$ |

| | | |
|---|---|---|
| | | WIP Inventories, $C_{52}$ |
| | | Adherence to Schedule, $C_{53}$ |
| | | Cost Per Unit Produced, $C_{54}$ |
| | | Setups/Changeovers, $C_{55}$ |
| | | Setup/Changeover Costs, $C_{56}$ |
| | | Unplanned Stockroom Issues, $C_{57}$ |
| | | Bill-of-Materials Accuracy, $C_{58}$ |
| | | Routing Accuracy, $C_{59}$ |
| | | Plant Space Utilization, $C_{5,10}$ |
| | | Line Breakdowns, $C_{5,11}$ |
| | | Warranty Costs, $C_{5,12}$ |
| | | Source-to-make-Cycle Time, $C_{5,13}$ |
| | | Percent Scrap/Rework, $C_{5,14}$ |
| | | Material Usage Variance, $C_{5,15}$ |
| | | Overtime Usage, $C_{5,16}$ |
| | | Production Cycle Time, $C_{5,17}$ |
| | | Manufacturing Productivity, $C_{5,18}$ |
| | | Master Schedule Stability, $C_{5,19}$ |
| | Marketing Management, $C_6$ | Market Share, $C_{61}$ |
| | | Percent of Sales from New Products, $C_{62}$ |
| | | Time-To-Market, $C_{63}$ |
| | | Repeat versus New Customer Sales, $C_{64}$ |
| | Extended Enterprise Measures, $C_7$ | Total Landed Cost, $C_{71}$ |
| | | Point of Consumption Product Availability, $C_{72}$ |
| | | Total Supply Chain Inventory, $C_{73}$ |
| | | Retail Shelf Display, $C_{74}$ |
| | | Channel Inventories, $C_{75}$ |
| | | EDI Transactions, $C_{76}$ |
| | | Percent of Demand/Supply on VMI/CRP, $C_{77}$ |
| | | Percent of Customers Sharing Forecasts, $C_{78}$ |
| | | Percent of Suppliers Getting Shared Forecast, $C_{79}$ |
| | | Supplier Inventories, $C_{7,10}$ |
| | | Internet Activity to Suppliers/Customers, $C_{7,11}$ |
| | | Percent Automated Tendering, $C_{7,12}$ |
| | Logistics Performance, $C_8$ | Finished Goods Inventory Turns, $C_{81}$ |

| | | |
|---|---|---|
| | | Finished Goods Inventory Days of Supply, $C_{82}$ |
| | | On-Time Delivery, $C_{83}$ |
| | | Lines Picked/Hour, $C_{84}$ |
| | | Damaged Shipments, $C_{85}$ |
| | | Inventory Accuracy, $C_{86}$ |
| | | Pick Accuracy, $C_{87}$ |
| | | Logistics Cost, $C_{88}$ |
| | | Shipment Accuracy, $C_{89}$ |
| | | On-Time Shipment, $C_{8,10}$ |
| | | Delivery Times, $C_{8,11}$ |
| | | Warehouse Space Utilization, $C_{8,12}$ |
| | | End-of-Life Inventory, $C_{8,13}$ |
| | | Obsolete Inventory, $C_{8,14}$ |
| | | Inventory Shrinkage, $C_{8,15}$ |
| | | Cost of Carrying/Holding Inventory, $C_{8,16}$ |
| | | Documentation Accuracy, $C_{8,17}$ |
| | | Transportation Cost, $C_{8,18}$ |
| | | Warehousing Costs, $C_{8,19}$ |
| | | Container Utilization, $C_{8,20}$ |
| | | Truck Cube Utilization, $C_{8,21}$ |
| | | In-Transit Inventories, $C_{8,22}$ |
| | | Premium Freight Charges, $C_{8,23}$ |
| | | Warehouse Receipts, $C_{8,24}$ |

Table 6.2.1: The scale of attribute weights $\otimes w$

| Scale | $\otimes w$ |
|---|---|
| Very Low (VL) | [0.0, 0.1] |
| Low (L) | [0.1, 0.3] |
| Medium Low (ML) | [0.3, 0.4] |
| Medium (M) | [0.4, 0.5] |
| Medium High (MH) | [0.5, 0.6] |
| High (H) | [0.6, 0.9] |
| Very High (VH) | [0.9, 1.0] |

Table 6.2.2: The scale of attribute ratings $\otimes G$

| Scale | $\otimes w$ |
|---|---|
| Very Poor (VP) | [0, 1] |
| Poor (P) | [1, 3] |
| Medium Poor (MP) | [3, 4] |
| Medium (M) | [4, 5] |
| Medium Good (MG) | [5, 6] |
| Good (G) | [6, 9] |
| Very Good (VG) | [9, 10] |

Table 6.3: Priority Weight (in linguistic scale) of $2^{nd}$ level indices assigned by DMs

| $2^{nd}$ level indices | Priority Weight (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | H | H | H | H | VH |
| $C_{12}$ | H | H | MH | H | H |
| $C_{13}$ | H | H | H | H | H |
| $C_{14}$ | VH | H | VH | H | H |
| $C_{15}$ | H | H | H | VH | VH |
| $C_{16}$ | H | H | H | VH | H |
| $C_{17}$ | MH | H | H | H | H |
| $C_{18}$ | VH | VH | H | H | VH |
| $C_{19}$ | VH | H | H | H | VH |
| $C_{1,10}$ | MH | H | H | H | H |
| $C_{1,11}$ | H | H | H | H | H |
| $C_{21}$ | VH | H | VH | H | H |
| $C_{22}$ | H | VH | H | VH | VH |
| $C_{23}$ | H | H | H | VH | H |
| $C_{24}$ | MH | H | H | H | H |
| $C_{25}$ | VH | VH | H | H | VH |
| $C_{26}$ | VH | H | H | H | VH |
| $C_{27}$ | MH | H | H | H | H |
| $C_{31}$ | H | H | H | H | H |
| $C_{32}$ | VH | H | H | H | H |
| $C_{33}$ | H | VH | H | VH | VH |
| $C_{34}$ | H | H | H | H | H |
| $C_{35}$ | MH | H | H | H | H |
| $C_{36}$ | VH | VH | H | H | VH |
| $C_{37}$ | VH | H | H | H | VH |
| $C_{38}$ | MH | H | H | H | H |
| $C_{41}$ | H | H | H | H | H |
| $C_{42}$ | VH | H | H | H | H |
| $C_{43}$ | H | VH | H | VH | VH |
| $C_{44}$ | H | H | H | VH | H |
| $C_{45}$ | MH | H | H | H | H |

| Table 6.3 (Continued) | | | | | |
|---|---|---|---|---|---|
| $2^{nd}$ level indices | Priority Weight (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{46}$ | VH | VH | H | H | H |
| $C_{51}$ | VH | H | H | H | VH |
| $C_{52}$ | MH | H | MH | H | H |
| $C_{53}$ | H | H | H | H | H |
| $C_{54}$ | VH | H | H | H | H |
| $C_{55}$ | H | VH | H | VH | VH |
| $C_{56}$ | H | H | H | VH | H |
| $C_{57}$ | MH | H | H | H | H |
| $C_{58}$ | VH | VH | H | H | VH |
| $C_{59}$ | VH | H | H | H | VH |
| $C_{5,10}$ | MH | H | H | H | H |
| $C_{5,11}$ | H | H | H | H | H |
| $C_{5,12}$ | VH | H | H | H | H |
| $C_{5,13}$ | H | VH | H | VH | VH |
| $C_{5,14}$ | H | H | H | VH | H |
| $C_{5,15}$ | MH | H | H | H | H |
| $C_{5,16}$ | VH | VH | H | H | VH |
| $C_{5,17}$ | VH | H | H | H | H |
| $C_{5,18}$ | MH | H | MH | H | H |
| $C_{5,19}$ | H | H | H | H | H |
| $C_{61}$ | VH | H | VH | H | H |
| $C_{62}$ | H | VH | H | VH | VH |
| $C_{63}$ | H | H | H | VH | H |
| $C_{64}$ | MH | H | H | H | H |
| $C_{71}$ | VH | VH | H | H | VH |
| $C_{72}$ | VH | H | H | H | VH |
| $C_{73}$ | MH | H | H | H | H |
| $C_{74}$ | H | H | H | H | H |
| $C_{75}$ | VH | H | VH | H | H |
| $C_{76}$ | H | VH | H | VH | VH |
| $C_{77}$ | H | H | H | VH | H |
| $C_{78}$ | MH | H | H | H | H |

Table 6.3 (Continued)

| $2^{nd}$ level indices | Priority Weight (in linguistic scale) of $2^{nd}$ level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{79}$ | VH | VH | H | H | VH |
| $C_{7,10}$ | VH | H | H | H | VH |
| $C_{7,11}$ | MH | H | MH | H | H |
| $C_{7,12}$ | H | H | H | H | H |
| $C_{81}$ | VH | H | VH | H | H |
| $C_{82}$ | H | VH | H | VH | VH |
| $C_{83}$ | H | H | H | VH | H |
| $C_{84}$ | MH | H | H | H | H |
| $C_{85}$ | VH | VH | H | H | VH |
| $C_{86}$ | VH | H | H | H | VH |
| $C_{87}$ | MH | H | H | H | H |
| $C_{88}$ | H | H | H | H | H |
| $C_{89}$ | VH | H | H | H | H |
| $C_{8,10}$ | H | VH | H | VH | VH |
| $C_{8,11}$ | H | H | H | VH | H |
| $C_{8,12}$ | H | H | H | H | H |
| $C_{8,13}$ | H | VH | H | H | VH |
| $C_{8,14}$ | VH | H | H | H | VH |
| $C_{8,15}$ | MH | H | MH | H | H |
| $C_{8,16}$ | H | H | H | H | H |
| $C_{8,17}$ | VH | H | VH | H | H |
| $C_{8,18}$ | H | VH | H | VH | H |
| $C_{8,19}$ | H | H | H | H | H |
| $C_{8,20}$ | MH | H | H | H | H |
| $C_{8,21}$ | VH | VH | H | H | VH |
| $C_{8,22}$ | VH | H | H | H | VH |
| $C_{8,23}$ | MH | H | MH | H | H |
| $C_{8,24}$ | H | H | H | H | H |

Table 6.4: Priority Weight (in linguistic scale) of $1^{st}$ level indices assigned by DMs

| $1^{st}$ level indices | Priority Weight (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_1$ | VH | H | H | H | VH |
| $C_2$ | MH | H | MH | H | H |
| $C_3$ | H | H | H | H | H |
| $C_4$ | VH | H | VH | H | H |
| $C_5$ | H | VH | H | VH | VH |
| $C_6$ | H | H | H | VH | H |
| $C_7$ | MH | H | H | H | H |
| $C_8$ | VH | VH | H | H | VH |

Table 6.5: Appropriateness rating (in linguistic scale) of $2^{nd}$ level indices assigned by DMs **(Alternative 1)**

| $2^{nd}$ level indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | MP | MP | MP | P | MP |
| $C_{12}$ | M | M | M | M | M |
| $C_{13}$ | MG | MG | G | MG | MG |
| $C_{14}$ | G | MG | G | G | G |
| $C_{15}$ | MP | M | MG | MG | MG |
| $C_{16}$ | G | G | G | G | MG |
| $C_{17}$ | G | G | G | G | G |
| $C_{18}$ | VG | G | VG | G | G |
| $C_{19}$ | G | G | G | G | G |
| $C_{1,10}$ | P | MP | MP | P | MP |
| $C_{1,11}$ | M | M | M | M | M |
| $C_{21}$ | G | MG | G | MG | MG |
| $C_{22}$ | G | G | G | G | G |
| $C_{23}$ | MP | M | MG | MG | G |
| $C_{24}$ | G | G | G | G | MG |
| $C_{25}$ | G | G | G | G | G |

| Table 6.5 (Continued) | | | | | |
|---|---|---|---|---|---|
| $2^{nd}$ level indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{26}$ | VG | G | VG | G | G |
| $C_{27}$ | MP | MP | MP | P | P |
| $C_{31}$ | G | VG | G | G | VG |
| $C_{32}$ | MP | MP | P | P | MP |
| $C_{33}$ | M | M | M | M | M |
| $C_{34}$ | G | G | G | MG | MG |
| $C_{35}$ | G | G | G | G | G |
| $C_{36}$ | MP | M | G | MG | G |
| $C_{37}$ | G | G | G | G | MG |
| $C_{38}$ | G | G | G | G | G |
| $C_{41}$ | VG | G | VG | G | G |
| $C_{42}$ | MP | P | MP | P | P |
| $C_{43}$ | G | G | VG | G | G |
| $C_{44}$ | G | G | G | G | G |
| $C_{45}$ | P | P | MP | P | MP |
| $C_{46}$ | M | M | M | M | M |
| $C_{51}$ | G | MG | G | MG | MG |
| $C_{52}$ | G | G | G | G | G |
| $C_{53}$ | MP | M | MG | MG | G |
| $C_{54}$ | G | G | G | G | MG |
| $C_{55}$ | G | G | G | G | G |
| $C_{56}$ | VG | G | G | G | G |
| $C_{57}$ | MP | MP | P | P | P |
| $C_{58}$ | G | VG | G | G | VG |
| $C_{59}$ | MP | MP | P | P | MP |
| $C_{5,10}$ | M | M | M | M | M |
| $C_{5,11}$ | G | G | G | G | MG |
| $C_{5,12}$ | G | G | G | G | G |
| $C_{5,13}$ | VG | G | VG | G | G |
| $C_{5,14}$ | G | G | G | G | G |
| $C_{5,15}$ | P | MP | MP | MP | MP |
| $C_{5,16}$ | P | M | MG | MG | G |

| Table 6.5 (Continued) | | | | | |
|---|---|---|---|---|---|
| 2nd level indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{5,17}$ | G | G | G | G | MG |
| $C_{5,18}$ | G | G | G | G | G |
| $C_{5,19}$ | VG | G | G | G | G |
| $C_{61}$ | MP | MP | P | P | P |
| $C_{62}$ | G | G | G | G | VG |
| $C_{63}$ | MP | P | P | P | MP |
| $C_{64}$ | M | M | M | M | M |
| $C_{71}$ | G | G | G | G | MG |
| $C_{72}$ | G | G | G | G | G |
| $C_{73}$ | VG | G | G | G | G |
| $C_{74}$ | G | G | G | G | G |
| $C_{75}$ | P | MP | MP | P | P |
| $C_{76}$ | G | MG | G | G | MG |
| $C_{77}$ | G | G | G | G | G |
| $C_{78}$ | VG | VG | VG | G | G |
| $C_{79}$ | G | G | G | G | G |
| $C_{7,10}$ | P | P | MP | MP | MP |
| $C_{7,11}$ | P | M | MG | MG | G |
| $C_{7,12}$ | G | G | G | G | MG |
| $C_{81}$ | G | G | G | VG | G |
| $C_{82}$ | VG | G | G | G | G |
| $C_{83}$ | MP | MP | P | MP | MP |
| $C_{84}$ | G | G | G | G | VG |
| $C_{85}$ | MP | P | P | P | MP |
| $C_{86}$ | M | M | M | MP | M |
| $C_{87}$ | G | G | G | G | MG |
| $C_{88}$ | G | G | G | G | G |
| $C_{89}$ | VG | G | VG | G | G |
| $C_{8,10}$ | G | G | G | G | G |
| $C_{8,11}$ | P | P | MP | MP | MP |
| $C_{8,12}$ | P | M | MG | MG | G |
| $C_{8,13}$ | G | G | VG | G | MG |

| Table 6.5 (Continued) | | | | | |
|---|---|---|---|---|---|
| $2^{nd}$ level indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{8,14}$ | G | G | G | VG | G |
| $C_{8,15}$ | VG | G | VG | G | G |
| $C_{8,16}$ | MP | MP | P | MP | MP |
| $C_{8,17}$ | G | G | G | G | VG |
| $C_{8,18}$ | MP | P | P | P | MP |
| $C_{8,19}$ | VG | VG | VG | VG | G |
| $C_{8,20}$ | G | G | G | VG | G |
| $C_{8,21}$ | P | P | MP | P | MP |
| $C_{8,22}$ | P | M | MG | MG | G |
| $C_{8,23}$ | G | G | G | G | G |
| $C_{8,24}$ | G | G | G | G | G |

Table 6.6: Appropriateness rating (in linguistic scale) of $2^{nd}$ level indices assigned by DMs **(Alternative 2)**

| $2^{nd}$ level indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | VG | VG | VG | G | VG |
| $C_{12}$ | G | G | G | G | VG |
| $C_{13}$ | MG | G | G | G | G |
| $C_{14}$ | G | G | G | G | VG |
| $C_{15}$ | VG | VG | VG | VG | VG |
| $C_{16}$ | VG | G | VG | G | VG |
| $C_{17}$ | G | G | G | G | G |
| $C_{18}$ | MG | M | G | M | M |
| $C_{19}$ | G | G | G | G | G |
| $C_{1,10}$ | G | G | G | G | G |
| $C_{1,11}$ | VG | VG | G | G | G |
| $C_{21}$ | G | VG | G | VG | G |
| $C_{22}$ | MG | MG | G | G | G |

| Table 6.6 (Continued) | | | | | |
|---|---|---|---|---|---|
| $2^{nd}$ level indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{23}$ | G | G | G | VG | VG |
| $C_{24}$ | MG | G | G | G | G |
| $C_{25}$ | G | VG | G | VG | G |
| $C_{26}$ | G | G | G | G | G |
| $C_{27}$ | G | G | VG | G | G |
| $C_{31}$ | MG | M | G | G | M |
| $C_{32}$ | G | G | G | VG | G |
| $C_{33}$ | G | G | G | G | G |
| $C_{34}$ | VG | VG | G | G | G |
| $C_{35}$ | G | VG | G | VG | G |
| $C_{36}$ | MG | MG | G | VG | G |
| $C_{37}$ | MG | G | G | G | G |
| $C_{38}$ | G | G | G | G | VG |
| $C_{41}$ | G | VG | VG | VG | VG |
| $C_{42}$ | G | G | VG | G | VG |
| $C_{43}$ | G | G | G | G | G |
| $C_{44}$ | M | M | G | M | M |
| $C_{45}$ | G | G | G | G | G |
| $C_{46}$ | G | G | G | G | G |
| $C_{51}$ | VG | G | G | G | G |
| $C_{52}$ | MG | G | G | G | G |
| $C_{53}$ | G | VG | G | VG | G |
| $C_{54}$ | G | G | G | G | G |
| $C_{55}$ | G | G | VG | G | G |
| $C_{56}$ | MG | M | G | G | M |
| $C_{57}$ | G | G | VG | VG | G |
| $C_{58}$ | G | G | VG | G | G |
| $C_{59}$ | VG | VG | VG | G | G |
| $C_{5,10}$ | G | VG | G | VG | G |
| $C_{5,11}$ | MG | MG | G | VG | G |
| $C_{5,12}$ | MG | G | G | G | G |
| $C_{5,13}$ | G | G | G | G | VG |

| Table 6.6 (Continued) | | | | | |
|---|---|---|---|---|---|
| $2^{nd}$ level indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{5,14}$ | G | VG | G | VG | VG |
| $C_{5,15}$ | G | G | G | G | VG |
| $C_{5,16}$ | MG | G | VG | G | G |
| $C_{5,17}$ | G | VG | VG | VG | VG |
| $C_{5,18}$ | MG | G | G | G | G |
| $C_{5,19}$ | G | VG | G | VG | G |
| $C_{61}$ | G | G | G | G | G |
| $C_{62}$ | G | G | VG | G | G |
| $C_{63}$ | MG | M | G | G | MG |
| $C_{64}$ | G | G | VG | VG | G |
| $C_{71}$ | G | G | VG | G | G |
| $C_{72}$ | VG | VG | VG | G | VG |
| $C_{73}$ | G | VG | G | VG | VG |
| $C_{74}$ | MG | MG | G | VG | VG |
| $C_{75}$ | MG | G | G | G | VG |
| $C_{76}$ | G | G | VG | G | G |
| $C_{77}$ | VG | VG | VG | G | G |
| $C_{78}$ | G | VG | G | VG | G |
| $C_{79}$ | MG | MG | G | VG | G |
| $C_{7,10}$ | MG | G | G | G | G |
| $C_{7,11}$ | G | G | G | G | VG |
| $C_{7,12}$ | G | G | G | VG | VG |
| $C_{81}$ | G | G | G | G | VG |
| $C_{82}$ | MG | G | VG | G | G |
| $C_{83}$ | G | VG | VG | VG | VG |
| $C_{84}$ | G | G | G | G | G |
| $C_{85}$ | G | VG | G | VG | G |
| $C_{86}$ | G | G | VG | G | G |
| $C_{87}$ | G | VG | VG | G | G |
| $C_{88}$ | VG | VG | VG | VG | VG |
| $C_{89}$ | G | MG | G | VG | G |
| $C_{8,10}$ | G | G | G | G | G |

Table 6.6 (Continued)

| $2^{nd}$ level indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{8,11}$ | G | G | G | G | VG |
| $C_{8,12}$ | G | G | G | VG | VG |
| $C_{8,13}$ | G | G | G | G | VG |
| $C_{8,14}$ | G | G | VG | G | G |
| $C_{8,15}$ | G | G | VG | G | G |
| $C_{8,16}$ | G | VG | G | VG | G |
| $C_{8,17}$ | G | G | VG | G | G |
| $C_{8,18}$ | G | VG | G | G | G |
| $C_{8,19}$ | VG | G | VG | G | G |
| $C_{8,20}$ | G | G | G | VG | G |
| $C_{8,21}$ | G | G | G | G | G |
| $C_{8,22}$ | G | G | G | G | VG |
| $C_{8,23}$ | G | VG | G | VG | G |
| $C_{8,24}$ | G | G | G | G | G |

Table 6.7: Appropriateness rating (in linguistic scale) of $2^{nd}$ level indices assigned by DMs **(Alternative 3)**

| $2^{nd}$ level indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | P | P | P | P | P |
| $C_{12}$ | MP | MP | P | MP | MP |
| $C_{13}$ | VP | P | MP | M | M |
| $C_{14}$ | VP | P | P | P | P |
| $C_{15}$ | M | M | MP | MP | MP |
| $C_{16}$ | MP | M | MP | M | M |
| $C_{17}$ | M | M | M | M | M |
| $C_{18}$ | M | MG | M | M | M |
| $C_{19}$ | MP | MP | MP | MP | MP |
| $C_{1,10}$ | P | P | P | P | P |
| $C_{1,11}$ | M | P | P | P | M |
| $C_{21}$ | MP | MP | MP | M | M |

| Table 6.7 (Continued) | | | | | |
|---|---|---|---|---|---|
| $2^{nd}$ level indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{22}$ | P | MP | P | P | P |
| $C_{23}$ | MP | MP | P | MP | MP |
| $C_{24}$ | VP | MP | MP | M | M |
| $C_{25}$ | VP | P | P | P | P |
| $C_{26}$ | M | M | MP | MP | MP |
| $C_{27}$ | MP | M | MP | M | M |
| $C_{31}$ | M | M | M | M | M |
| $C_{32}$ | M | MG | M | M | M |
| $C_{33}$ | MP | MP | P | MP | MP |
| $C_{34}$ | P | P | MP | P | P |
| $C_{35}$ | M | P | P | P | M |
| $C_{36}$ | MP | MP | MP | M | M |
| $C_{37}$ | P | P | MP | P | P |
| $C_{38}$ | M | MG | M | M | M |
| $C_{41}$ | MP | MP | MP | MP | MP |
| $C_{42}$ | P | P | P | P | P |
| $C_{43}$ | M | P | MP | P | M |
| $C_{44}$ | MP | MP | MP | M | M |
| $C_{45}$ | P | MP | P | P | P |
| $C_{46}$ | MP | MP | P | P | MP |
| $C_{51}$ | VP | MP | MP | MG | M |
| $C_{52}$ | MP | M | MP | M | M |
| $C_{53}$ | M | M | M | M | M |
| $C_{54}$ | M | MG | M | M | M |
| $C_{55}$ | MP | MP | P | MP | MP |
| $C_{56}$ | P | P | MP | P | P |
| $C_{57}$ | M | P | P | P | M |
| $C_{58}$ | MP | MP | P | M | M |
| $C_{59}$ | P | P | P | P | P |
| $C_{5,10}$ | M | MG | M | M | M |
| $C_{5,11}$ | MP | MP | M | MP | MP |
| $C_{5,12}$ | P | P | P | P | P |

| Table 6.7 (Continued) | | | | | |
|---|---|---|---|---|---|
| $2^{nd}$ level indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{5,13}$ | MP | M | M | M | M |
| $C_{5,14}$ | M | M | M | M | M |
| $C_{5,15}$ | M | MG | MG | M | M |
| $C_{5,16}$ | MP | M | MP | M | M |
| $C_{5,17}$ | M | M | M | M | M |
| $C_{5,18}$ | M | MG | M | M | M |
| $C_{5,19}$ | MP | MP | P | MP | MP |
| $C_{61}$ | P | MP | MP | P | P |
| $C_{62}$ | M | P | P | P | MP |
| $C_{63}$ | MP | MP | MP | M | M |
| $C_{64}$ | P | P | MP | P | P |
| $C_{71}$ | M | MG | M | M | M |
| $C_{72}$ | MP | MP | MP | MP | P |
| $C_{73}$ | P | P | P | P | MP |
| $C_{74}$ | MP | M | MP | M | MP |
| $C_{75}$ | M | M | M | M | MP |
| $C_{76}$ | MP | M | MP | MP | M |
| $C_{77}$ | M | M | M | M | M |
| $C_{78}$ | M | MG | M | M | M |
| $C_{79}$ | MP | MP | P | MP | MP |
| $C_{7,10}$ | P | P | MP | P | P |
| $C_{7,11}$ | M | P | P | P | M |
| $C_{7,12}$ | MP | MP | MP | M | M |
| $C_{81}$ | P | P | MP | P | P |
| $C_{82}$ | M | M | M | M | M |
| $C_{83}$ | MP | P | MP | MP | MP |
| $C_{84}$ | P | P | P | MP | P |
| $C_{85}$ | MP | M | MP | M | M |
| $C_{86}$ | M | M | M | M | M |
| $C_{87}$ | MP | MG | M | M | M |
| $C_{88}$ | MP | MP | P | MP | MP |
| $C_{89}$ | P | P | MP | P | P |

| Table 6.7 (Continued) | | | | | |
|---|---|---|---|---|---|
| $2^{nd}$ level indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{8,10}$ | M | P | P | P | M |
| $C_{8,11}$ | MP | MP | MP | M | M |
| $C_{8,12}$ | P | P | P | P | P |
| $C_{8,13}$ | MP | M | MP | M | M |
| $C_{8,14}$ | M | M | M | M | M |
| $C_{8,15}$ | M | MG | MG | M | M |
| $C_{8,16}$ | MP | MP | P | MP | MP |
| $C_{8,17}$ | P | P | MP | P | P |
| $C_{8,18}$ | M | P | P | P | M |
| $C_{8,19}$ | MP | MP | MP | M | M |
| $C_{8,20}$ | P | P | MP | P | P |
| $C_{8,21}$ | M | MG | M | M | M |
| $C_{8,22}$ | MP | MP | M | MP | MP |
| $C_{8,23}$ | P | P | P | P | P |
| $C_{8,24}$ | M | M | MP | MP | MP |

Table 6.8: Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs **(Alternative 4)**

| 2nd level indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
|---|---|---|---|---|---|
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{11}$ | G | G | VG | VG | VG |
| $C_{12}$ | G | VG | VG | VG | G |
| $C_{13}$ | G | G | G | G | G |
| $C_{14}$ | VG | VG | VG | VG | G |
| $C_{15}$ | MG | G | G | G | G |
| $C_{16}$ | G | VG | MG | VG | VG |
| $C_{17}$ | MG | G | G | G | MG |
| $C_{18}$ | VG | G | VG | G | G |
| $C_{19}$ | MG | MG | MG | G | G |
| $C_{1,10}$ | G | VG | G | VG | VG |
| $C_{1,11}$ | MG | MG | MG | G | G |
| $C_{21}$ | G | G | G | VG | VG |
| $C_{22}$ | G | G | VG | VG | G |
| $C_{23}$ | G | MG | G | MG | G |
| $C_{24}$ | MG | G | G | MG | MG |
| $C_{25}$ | G | G | G | MG | MG |
| $C_{26}$ | VG | VG | G | G | G |
| $C_{27}$ | MG | G | MG | G | MG |
| $C_{31}$ | G | G | G | G | G |
| $C_{32}$ | G | G | G | MG | MG |
| $C_{33}$ | G | VG | VG | VG | G |
| $C_{34}$ | M | M | M | MG | MG |
| $C_{35}$ | G | G | G | G | G |
| $C_{36}$ | MG | MG | G | G | G |
| $C_{37}$ | G | G | G | G | MG |
| $C_{38}$ | VG | VG | VG | G | G |
| $C_{41}$ | G | VG | G | VG | G |
| $C_{42}$ | MG | MG | VG | VG | VG |
| $C_{43}$ | VG | VG | VG | VG | G |
| $C_{44}$ | MG | G | G | G | G |
| $C_{45}$ | G | VG | G | VG | G |

| Table 6.8 (Continued) | | | | | |
|---|---|---|---|---|---|
| $2^{nd}$ level indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{46}$ | G | G | G | G | MG |
| $C_{51}$ | VG | G | VG | G | G |
| $C_{52}$ | MG | MG | MG | G | G |
| $C_{53}$ | G | VG | G | G | VG |
| $C_{54}$ | MG | MG | G | G | G |
| $C_{55}$ | G | G | G | VG | VG |
| $C_{56}$ | G | G | VG | VG | G |
| $C_{57}$ | G | MG | G | MG | G |
| $C_{58}$ | M | M | M | G | MG |
| $C_{59}$ | G | G | G | G | G |
| $C_{5,10}$ | MG | MG | G | G | MG |
| $C_{5,11}$ | G | G | G | G | MG |
| $C_{5,12}$ | VG | VG | VG | G | G |
| $C_{5,13}$ | G | VG | G | VG | G |
| $C_{5,14}$ | MG | MG | G | VG | VG |
| $C_{5,15}$ | VG | VG | G | VG | VG |
| $C_{5,16}$ | MG | G | G | G | VG |
| $C_{5,17}$ | G | VG | G | VG | VG |
| $C_{5,18}$ | MG | G | G | G | G |
| $C_{5,19}$ | G | G | G | VG | G |
| $C_{61}$ | G | G | G | G | MG |
| $C_{62}$ | VG | G | VG | G | G |
| $C_{63}$ | G | MG | MG | G | G |
| $C_{64}$ | G | VG | G | G | VG |
| $C_{71}$ | G | MG | G | G | G |
| $C_{72}$ | G | G | G | VG | VG |
| $C_{73}$ | G | G | VG | VG | G |
| $C_{74}$ | G | MG | G | MG | G |
| $C_{75}$ | M | M | M | G | MG |
| $C_{76}$ | VG | G | VG | VG | G |
| $C_{77}$ | MG | MG | G | G | G |
| $C_{78}$ | G | VG | G | G | VG |

| Table 6.8 (Continued) | | | | | |
|---|---|---|---|---|---|
| 2nd level indices | Appropriateness rating (in linguistic scale) of 2nd level indices assigned by DMs | | | | |
| | DM1 | DM2 | DM3 | DM4 | DM5 |
| $C_{79}$ | MG | MG | G | G | G |
| $C_{7,10}$ | G | G | G | VG | VG |
| $C_{7,11}$ | G | G | VG | VG | G |
| $C_{7,12}$ | G | MG | G | MG | G |
| $C_{81}$ | M | M | M | G | MG |
| $C_{82}$ | G | G | G | G | G |
| $C_{83}$ | MG | G | G | G | MG |
| $C_{84}$ | G | G | G | G | MG |
| $C_{85}$ | VG | VG | VG | G | G |
| $C_{86}$ | G | VG | G | G | G |
| $C_{87}$ | MG | MG | G | G | VG |
| $C_{88}$ | VG | VG | G | G | VG |
| $C_{89}$ | MG | G | G | G | VG |
| $C_{8,10}$ | G | VG | G | G | VG |
| $C_{8,11}$ | VG | VG | VG | VG | G |
| $C_{8,12}$ | G | G | VG | G | G |
| $C_{8,13}$ | G | VG | VG | G | VG |
| $C_{8,14}$ | MG | MG | G | G | G |
| $C_{8,15}$ | G | G | G | VG | VG |
| $C_{8,16}$ | G | G | VG | VG | G |
| $C_{8,17}$ | G | MG | G | G | VG |
| $C_{8,18}$ | M | M | M | G | G |
| $C_{8,19}$ | G | G | G | G | G |
| $C_{8,20}$ | MG | G | G | G | G |
| $C_{8,21}$ | G | G | G | G | G |
| $C_{8,22}$ | VG | VG | VG | G | VG |
| $C_{8,23}$ | VG | G | VG | VG | VG |
| $C_{8,24}$ | MG | MG | G | G | MG |

Table 6.9: Grey aggregated priority weight of 2nd level attributes

| 2nd level attributes ($C_{ij}$) | Weight ($w_{ij}$) | Grey aggregated priority weight(values) |
|---|---|---|
| $C_{11}$ | $w_{11}$ | [0.78, 0.92] |
| $C_{12}$ | $w_{12}$ | [0.58, 0.84] |
| $C_{13}$ | $w_{13}$ | [0.60, 0.90] |
| $C_{14}$ | $w_{14}$ | [0.72, 0.94] |
| $C_{15}$ | $w_{15}$ | [0.72, 0.94] |
| $C_{16}$ | $w_{16}$ | [0.78, 0.92] |
| $C_{17}$ | $w_{17}$ | [0.58, 0.84] |
| $C_{18}$ | $w_{18}$ | [0.78, 0.96] |
| $C_{19}$ | $w_{19}$ | [0.72, 0.94] |
| $C_{1,10}$ | $w_{1,10}$ | [0.58, 0.84] |
| $C_{1,11}$ | $w_{1,11}$ | [0.60, 0.90] |
| $C_{21}$ | $w_{21}$ | [0.72, 0.94] |
| $C_{22}$ | $w_{22}$ | [0.78, 0.96] |
| $C_{23}$ | $w_{23}$ | [0.78, 0.92] |
| $C_{24}$ | $w_{24}$ | [0.58, 0.84] |
| $C_{25}$ | $w_{25}$ | [0.78, 0.96] |
| $C_{26}$ | $w_{26}$ | [0.72, 0.84] |
| $C_{27}$ | $w_{27}$ | [0.58, 0.84] |
| $C_{31}$ | $w_{31}$ | [0.60, 0.90] |
| $C_{32}$ | $w_{32}$ | [0.78, 0.92] |
| $C_{33}$ | $w_{33}$ | [0.78, 0.96] |
| $C_{34}$ | $w_{34}$ | [0.60, 0.90] |
| $C_{35}$ | $w_{35}$ | [0.58, 0.84] |
| $C_{36}$ | $w_{36}$ | [0.78, 0.96] |
| $C_{37}$ | $w_{37}$ | [0.72, 0.94] |
| $C_{38}$ | $w_{38}$ | [0.58, 0.84] |
| $C_{41}$ | $w_{41}$ | [0.60, 0.90] |
| $C_{42}$ | $w_{42}$ | [0.78, 0.92] |
| $C_{43}$ | $w_{43}$ | [0.78, 0.96] |
| $C_{44}$ | $w_{44}$ | [0.78, 0.92] |
| $C_{45}$ | $w_{45}$ | [0.58, 0.84] |

| Table 6.9 (Continued) | | |
|---|---|---|
| 2nd level attributes ($C_{ij}$) | Weight ($w_{ij}$) | Grey aggregated priority weight(values) |
| $C_{46}$ | $w_{46}$ | [0.72, 0.94] |
| $C_{51}$ | $w_{51}$ | [0.72, 0.94] |
| $C_{52}$ | $w_{52}$ | [0.56, 0.78] |
| $C_{53}$ | $w_{53}$ | [0.60, 0.90] |
| $C_{54}$ | $w_{54}$ | [0.78, 0.92] |
| $C_{55}$ | $w_{55}$ | [0.78, 0.96] |
| $C_{56}$ | $w_{56}$ | [0.78, 0.92] |
| $C_{57}$ | $w_{57}$ | [0.58, 0.84] |
| $C_{58}$ | $w_{58}$ | [0.78, 0.96] |
| $C_{59}$ | $w_{59}$ | [0.72, 0.94] |
| $C_{5,10}$ | $w_{5,10}$ | [0.58, 0.84] |
| $C_{5,11}$ | $w_{5,11}$ | [0.60, 0.90] |
| $C_{5,12}$ | $w_{5,12}$ | [0.78, 0.92] |
| $C_{5,13}$ | $w_{5,13}$ | [0.78, 0.96] |
| $C_{5,14}$ | $w_{5,14}$ | [0.78, 0.92] |
| $C_{5,15}$ | $w_{5,15}$ | [0.58, 0.84] |
| $C_{5,16}$ | $w_{5,16}$ | [0.78, 0.96] |
| $C_{5,17}$ | $w_{5,17}$ | [0.78, 0.92] |
| $C_{5,18}$ | $w_{5,18}$ | [0.56, 0.78] |
| $C_{5,19}$ | $w_{5,19}$ | [0.60, 0.90] |
| $C_{61}$ | $w_{61}$ | [0.72, 0.94] |
| $C_{62}$ | $w_{62}$ | [0.78, 0.96] |
| $C_{63}$ | $w_{63}$ | [0.78, 0.92] |
| $C_{64}$ | $w_{64}$ | [0.58, 0.84] |
| $C_{71}$ | $w_{71}$ | [0.78, 0.96] |
| $C_{72}$ | $w_{72}$ | [0.72, 0.94] |
| $C_{73}$ | $w_{73}$ | [0.58, 0.84] |
| $C_{74}$ | $w_{74}$ | [0.60, 0.90] |
| $C_{75}$ | $w_{75}$ | [0.72, 0.94] |
| $C_{76}$ | $w_{76}$ | [0.78, 0.96] |
| $C_{77}$ | $w_{77}$ | [0.78, 0.92] |
| $C_{78}$ | $w_{78}$ | [0.58, 0.84] |

| Table 6.9 (Continued) | | |
|---|---|---|
| $2^{nd}$ level attributes ($C_{ij}$) | $2^{nd}$ level attributes ($C_{ij}$) | $2^{nd}$ level attributes ($C_{ij}$) |
| $C_{79}$ | $w_{79}$ | [0.78, 0.96] |
| $C_{7,10}$ | $w_{7,10}$ | [0.72, 0.94] |
| $C_{7,11}$ | $w_{7,11}$ | [0.56, 0.78] |
| $C_{7,12}$ | $w_{7,12}$ | [0.60, 0.90] |
| $C_{81}$ | $w_{81}$ | [0.72, 0.94] |
| $C_{82}$ | $w_{82}$ | [0.78, 0.96] |
| $C_{83}$ | $w_{83}$ | [0.78, 0.92] |
| $C_{84}$ | $w_{84}$ | [0.58, 0.84] |
| $C_{85}$ | $w_{85}$ | [0.78, 0.96] |
| $C_{86}$ | $w_{86}$ | [0.72, 0.94] |
| $C_{87}$ | $w_{87}$ | [0.58, 0.84] |
| $C_{88}$ | $w_{88}$ | [0.60, 0.90] |
| $C_{89}$ | $w_{89}$ | [0.78, 0.92] |
| $C_{8,10}$ | $w_{8,10}$ | [0.78, 0.96] |
| $C_{8,11}$ | $w_{8,11}$ | [0.78, 0.92] |
| $C_{8,12}$ | $w_{8,12}$ | [0.60, 0.90] |
| $C_{8,13}$ | $w_{8,13}$ | [0.72, 0.94] |
| $C_{8,14}$ | $w_{8,14}$ | [0.72, 0.94] |
| $C_{8,15}$ | $w_{8,15}$ | [0.56, 0.78] |
| $C_{8,16}$ | $w_{8,16}$ | [0.60, 0.90] |
| $C_{8,17}$ | $w_{8,17}$ | [0.72, 0.94] |
| $C_{8,18}$ | $w_{8,18}$ | [0.72, 0.94] |
| $C_{8,19}$ | $w_{8,19}$ | [0.60, 0.90] |
| $C_{8,20}$ | $w_{8,20}$ | [0.58, 0.84] |
| $C_{8,21}$ | $w_{8,21}$ | [0.78, 0.96] |
| $C_{8,22}$ | $w_{8,22}$ | [0.72, 0.94] |
| $C_{8,23}$ | $w_{8,23}$ | [0.56, 0.78] |
| $C_{8,24}$ | $w_{8,24}$ | [0.60, 0.90] |

Table 6.10: Aggregated grey priority weight of 1st level attributes

| 1st level attributes ($C_i$) | Weight ($w_i$) | Aggregated grey priority weight(values) |
|---|---|---|
| $C_1$ | $w_1$ | [0.72, 0.94] |
| $C_2$ | $w_2$ | [0.56, 0.78] |
| $C_3$ | $w_3$ | [0.60, 0.90] |
| $C_4$ | $w_4$ | [0.72, 0.94] |
| $C_5$ | $w_5$ | [0.78, 0.96] |
| $C_6$ | $w_6$ | [0.78, 0.92] |
| $C_7$ | $w_7$ | [0.58, 0.84] |
| $C_8$ | $w_8$ | [0.78, 0.96] |

Table 6.11: Grey aggregated appropriateness rating on 2nd level attributes **(Alternative 1 & Alternative 2)**

| Grey aggregated appropriateness rating on attributes **(Alternative 1)** | | | | Grey aggregated appropriateness rating on attributes **(Alternative 2)** | | | |
|---|---|---|---|---|---|---|---|
| 2nd level attributes ($C_{ij}$) | Rating($U_{ij}$) | Grey aggregated appropriateness rating (values) ($U_{ij}$) | Grey aggregated weighted appropriateness rating (values) ($U_{ij} \otimes w_{ij}$) | 2nd level attributes ($C_{ij}$) | Rating($U_{ij}$) | Grey aggregated appropriateness rating (values) ($U_{ij}$) | Grey aggregated weighted appropriateness rating (values) ($U_{ij} \otimes w_{ij}$) |
| $C_{11}$ | $U_{11}$ | [2.60, 3.80] | [2.03,3.50] | $C_{11}$ | $U_{11}$ | [8.40, 9.80] | [6.55,9.02] |
| $C_{12}$ | $U_{12}$ | [4.00, 5.00] | [2.32,4.20] | $C_{12}$ | $U_{12}$ | [6.60, 9.20] | [3.83,7.73] |
| $C_{13}$ | $U_{13}$ | [5.20, 6.60] | [3.12,5.94] | $C_{13}$ | $U_{13}$ | [5.80, 8.40] | [3.48,7.56] |
| $C_{14}$ | $U_{14}$ | [5.80, 8.40] | [4.18,7.90] | $C_{14}$ | $U_{14}$ | [6.60, 9.20] | [4.75,8.56] |
| $C_{15}$ | $U_{15}$ | [4.40, 5.40] | [3.17,5.08] | $C_{15}$ | $U_{15}$ | [9.00, 10.0] | [6.48,9.40] |
| $C_{16}$ | $U_{16}$ | [5.80, 8.40] | [4.52,7.73] | $C_{16}$ | $U_{16}$ | [7.80, 9.60] | [6.08,8.83] |
| $C_{17}$ | $U_{17}$ | [6.00, 9.00] | [3.48,7.56] | $C_{17}$ | $U_{17}$ | [6.00, 9.00] | [3.48,7.56] |
| $C_{18}$ | $U_{18}$ | [7.20, 9.40] | [5.62,9.02] | $C_{18}$ | $U_{18}$ | [4.60, 6.00] | [3.59,5.76] |
| $C_{19}$ | $U_{19}$ | [6.00, 9.00] | [4.32, 8.46] | $C_{19}$ | $U_{19}$ | [6.00, 9.00] | [4.32,8.46] |
| $C_{1,10}$ | $U_{1,10}$ | [2.20, 3.60] | [1.28, 3.02] | $C_{1,10}$ | $U_{1,10}$ | [6.00, 9.00] | [3.48,7.56] |
| $C_{1,11}$ | $U_{1,11}$ | [4.00, 5.00] | [2.40, 4.50] | $C_{1,11}$ | $U_{1,11}$ | [7.20, 9.40] | [4.32,8.46] |
| $C_{21}$ | $U_{21}$ | [5.40, 7.20] | [3.89, 6.77] | $C_{21}$ | $U_{21}$ | [7.20,9.40] | [5.18,8.84] |
| $C_{22}$ | $U_{22}$ | [6.00, 9.00] | [4.68, 8.64] | $C_{22}$ | $U_{22}$ | [5.60, 7.80] | [4.37,7.49] |
| $C_{23}$ | $U_{23}$ | [4.60, 6.00] | [3.59, 5.52] | $C_{23}$ | $U_{23}$ | [7.20, 9.40] | [5.62,8.65] |
| $C_{24}$ | $U_{24}$ | [5.80, 8.40] | [3.36, 7.06] | $C_{24}$ | $U_{24}$ | [5.80, 8.40] | [3.36,7.06] |
| $C_{25}$ | $U_{25}$ | [6.00, 9.00] | [4.68, 8.64] | $C_{25}$ | $U_{25}$ | [7.20, 9.40] | [5.62,9.02] |
| $C_{26}$ | $U_{26}$ | [7.20, 9.40] | [5.18, 8.84] | $C_{26}$ | $U_{26}$ | [6.00, 9.00] | [4.32,8.46] |
| $C_{27}$ | $U_{27}$ | [2.20, 3.60] | [1.28, 3.02] | $C_{27}$ | $U_{27}$ | [6.60, 9.20] | [3.83,7.73] |
| $C_{31}$ | $U_{31}$ | [7.20, 9.40] | [4.32, 8.46] | $C_{31}$ | $U_{31}$ | [5.00, 6.80] | [3.00,6.12] |
| $C_{32}$ | $U_{32}$ | [2.20, 3.60] | [1.72, 3.31] | $C_{32}$ | $U_{32}$ | [6.60, 9.20] | [5.15,8.46] |
| $C_{33}$ | $U_{33}$ | [4.00, 5.00] | [3.12, 4.80] | $C_{33}$ | $U_{33}$ | [6.00, 9.00] | [4.68,8.64] |
| $C_{34}$ | $U_{34}$ | [5.60, 7.80] | [3.36, 7.02] | $C_{34}$ | $U_{34}$ | [7.20, 9.40] | [4.32,8.46] |
| $C_{35}$ | $U_{35}$ | [6.00, 9.00] | [3.48, 7.56] | $C_{35}$ | $U_{35}$ | [7.20, 9.40] | [4.18,7.90] |
| $C_{36}$ | $U_{36}$ | [4.80, 6.60] | [3.74, 6.34] | $C_{36}$ | $U_{36}$ | [6.20, 8.00] | [4.84,7.68] |
| $C_{37}$ | $U_{37}$ | [5.80, 8.40] | [4.18, 7.90] | $C_{37}$ | $U_{37}$ | [5.80, 8.40] | [4.18,7.90] |
| $C_{38}$ | $U_{38}$ | [6.00, 9.00] | [3.48, 7.56] | $C_{38}$ | $U_{38}$ | [6.60,9.20] | [3.83,7.73] |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $C_{41}$ | $U_{41}$ | [7.20, 9.40] | [4.32, 8.46] | $C_{41}$ | $U_{41}$ | [8.40,9.80] | [5.04,8.82] |
| $C_{42}$ | $U_{42}$ | [1.80, 9.40] | [1.40, 3.13] | $C_{42}$ | $U_{42}$ | [7.20,9.40] | [5.62,8.65] |
| $C_{43}$ | $U_{43}$ | [6.60, 9.20] | [5.15, 8.83] | $C_{43}$ | $U_{43}$ | [6.00,9.00] | [4.68,8.64] |
| $C_{44}$ | $U_{44}$ | [6.00, 9.00] | [4.68, 8.28] | $C_{44}$ | $U_{44}$ | [4.40,5.80] | [3.43,5.34] |
| $C_{45}$ | $U_{45}$ | [1.80, 3.40] | [1.04, 2.86] | $C_{45}$ | $U_{45}$ | [6.00,9.00] | [3.48,7.56] |
| $C_{46}$ | $U_{46}$ | [4.00, 5.00] | [2.88, 4.70] | $C_{46}$ | $U_{46}$ | [6.00,9.00] | [4.32,8.46] |
| $C_{51}$ | $U_{51}$ | [5.40, 7.20] | [3.89, 6.77] | $C_{51}$ | $U_{51}$ | [6.60,9.20] | [4.75,8.65] |
| $C_{52}$ | $U_{52}$ | [6.00, 9.00] | [3.36, 6.77] | $C_{52}$ | $U_{52}$ | [5.80,8.40] | [3.25,6.55] |
| $C_{53}$ | $U_{53}$ | [4.60, 6.00] | [2.76, 7.02] | $C_{53}$ | $U_{53}$ | [7.20,9.40] | [4.32,8.46] |
| $C_{54}$ | $U_{54}$ | [5.80, 8.40] | [4.52, 7.73] | $C_{54}$ | $U_{54}$ | [6.00,9.00] | [4.68,8.28] |
| $C_{55}$ | $U_{55}$ | [6.00, 9.00] | [4.68, 8.64] | $C_{55}$ | $U_{55}$ | [6.60,9.20] | [5.15,8.83] |
| $C_{56}$ | $U_{56}$ | [6.60, 9.20] | [5.15, 8.46] | $C_{56}$ | $U_{56}$ | [5.00,6.80] | [3.90,6.26] |
| $C_{57}$ | $U_{57}$ | [1.80, 3.40] | [1.04, 2.86] | $C_{57}$ | $U_{57}$ | [7.20,9.40] | [4.18,7.90] |
| $C_{58}$ | $U_{58}$ | [7.20, 9.40] | [5.62, 9.02] | $C_{58}$ | $U_{58}$ | [6.60,9.20] | [5.15,8.83] |
| $C_{59}$ | $U_{59}$ | [2.20, 3.60] | [1.58, 3.38] | $C_{59}$ | $U_{59}$ | [7.80,9.60] | [5.62,9.02] |
| $C_{5,10}$ | $U_{5,10}$ | [4.00, 5.00] | [2.32, 4.20] | $C_{5,10}$ | $U_{5,10}$ | [7.20,9.40] | [4.18,7.90] |
| $C_{5,11}$ | $U_{5,11}$ | [5.80, 8.40] | [3.48, 7.56] | $C_{5,11}$ | $U_{5,11}$ | [6.20,8.00] | [3.72,7.20] |
| $C_{5,12}$ | $U_{5,12}$ | [6.00, 9.00] | [4.68, 8.28] | $C_{5,12}$ | $U_{5,12}$ | [5.80,8.40] | [4.52,7.73] |
| $C_{5,13}$ | $U_{5,13}$ | [7.20, 9.40] | [5.62, 9.02] | $C_{5,13}$ | $U_{5,13}$ | [6.60,9.20] | [5.15,8.83] |
| $C_{5,14}$ | $U_{5,14}$ | [6.00, 9.00] | [4.68, 8.28] | $C_{5,14}$ | $U_{5,14}$ | [7.80,9.60] | [6.08,8.83] |
| $C_{5,15}$ | $U_{5,15}$ | [2.60, 3.80] | [1.51, 3.19] | $C_{5,15}$ | $U_{5,15}$ | [6.60,9.20] | [3.83,7.73] |
| $C_{5,16}$ | $U_{5,16}$ | [4.20, 5.80] | [3.28, 5.57] | $C_{5,16}$ | $U_{5,16}$ | [6.40,8.60] | [4.99,8.26] |
| $C_{5,17}$ | $U_{5,17}$ | [5.80, 8.40] | [4.52, 7.73] | $C_{5,17}$ | $U_{5,17}$ | [8.40,9.80] | [6.55,9.02] |
| $C_{5,18}$ | $U_{5,18}$ | [6.00, 9.00] | [3.36, 7.02] | $C_{5,18}$ | $U_{5,18}$ | [5.80,8.40] | [3.25,6.55] |
| $C_{5,19}$ | $U_{5,19}$ | [6.60, 9.20] | [3.96, 8.28] | $C_{5,19}$ | $U_{5,19}$ | [7.20,9.40] | [4.32,8.46] |
| $C_{61}$ | $U_{61}$ | [1.80, 3.40] | [1.30, 3.20] | $C_{61}$ | $U_{61}$ | [6.00,9.00] | [4.32,8.46] |
| $C_{62}$ | $U_{62}$ | [6.60, 9.20] | [5.15, 8.83] | $C_{62}$ | $U_{62}$ | [6.60,9.20] | [5.15,8.83] |
| $C_{63}$ | $U_{63}$ | [1.80, 3.40] | [1.40, 3.13] | $C_{63}$ | $U_{63}$ | [5.20,7.00] | [4.06,6.44] |
| $C_{64}$ | $U_{64}$ | [4.00, 5.00] | [2.32, 4.20] | $C_{64}$ | $U_{64}$ | [7.20,9.40] | [4.18,7.90] |
| $C_{71}$ | $U_{71}$ | [5.80, 8.40] | [4.52, 8.06] | $C_{71}$ | $U_{71}$ | [6.60,9.20] | [5.15,8.83] |
| $C_{72}$ | $U_{72}$ | [6.00, 9.00] | [4.32, 8.46] | $C_{72}$ | $U_{72}$ | [8.40,9.80] | [6.05,9.21] |
| $C_{73}$ | $U_{73}$ | [6.60, 9.20] | [3.83, 7.73] | $C_{73}$ | $U_{73}$ | [7.80,9.60] | [4.52,8.06] |
| $C_{74}$ | $U_{74}$ | [6.00, 9.00] | [3.60, 8.10] | $C_{74}$ | $U_{74}$ | [6.80,8.20] | [4.08,7.38] |
| $C_{75}$ | $U_{75}$ | [1.80, 3.40] | [1.30, 3.20] | $C_{75}$ | $U_{75}$ | [6.40,8.60] | [4.61,8.08] |
| $C_{76}$ | $U_{76}$ | [5.60, 7.80] | [4.37, 7.49] | $C_{76}$ | $U_{76}$ | [6.60,9.20] | [5.15,8.83] |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $C_{77}$ | $U_{77}$ | [6.00, 9.00] | [4.68, 8.28] | $C_{77}$ | $U_{77}$ | [7.80,9.60] | [6.08,8.83] |
| $C_{78}$ | $U_{78}$ | [7.80, 9.60] | [4.52, 8.06] | $C_{78}$ | $U_{78}$ | [7.20,9.40] | [4.18,7.90] |
| $C_{79}$ | $U_{79}$ | [6.00, 9.00] | [4.68, 8.64] | $C_{79}$ | $U_{79}$ | [7.20,9.40] | [5.62,9.02] |
| $C_{7,10}$ | $U_{7,10}$ | [2.20, 3.60] | [1.58, 3.38] | $C_{7,10}$ | $U_{7,10}$ | [5.80,8.40] | [4.18,7.90] |
| $C_{7,11}$ | $U_{7,11}$ | [4.20, 5.80] | [2.35, 4.52] | $C_{7,11}$ | $U_{7,11}$ | [6.60,9.20] | [3.70,7.18] |
| $C_{7,12}$ | $U_{7,12}$ | [5.80, 5.40] | [3.48, 7.56] | $C_{7,12}$ | $U_{7,12}$ | [7.20,9.40] | [4.32,8.46] |
| $C_{81}$ | $U_{81}$ | [6.60, 9.20] | [4.75, 8.65] | $C_{81}$ | $U_{81}$ | [6.60,9.20] | [4.75,8.65] |
| $C_{82}$ | $U_{82}$ | [6.60, 9.20] | [5.15, 8.83] | $C_{82}$ | $U_{82}$ | [6.40,8.60] | [4.99,8.26] |
| $C_{83}$ | $U_{83}$ | [2.60, 3.80] | [2.03, 3.50] | $C_{83}$ | $U_{83}$ | [8.40,9.80] | [6.55,9.02] |
| $C_{84}$ | $U_{84}$ | [6.60, 9.20] | [3.83, 7.73] | $C_{84}$ | $U_{84}$ | [6.00,9.00] | [3.48,7.56] |
| $C_{85}$ | $U_{85}$ | [1.80, 3.40] | [1.40, 3.26] | $C_{85}$ | $U_{85}$ | [7.20,9.40] | [5.62,9.02] |
| $C_{86}$ | $U_{86}$ | [3.80, 4.80] | [2.74, 4.51] | $C_{86}$ | $U_{86}$ | [6.60,9.20] | [4.75,8.65] |
| $C_{87}$ | $U_{87}$ | [5.80, 8.40] | [3.36, 7.06] | $C_{87}$ | $U_{87}$ | [7.20,9.40] | [4.18,7.90] |
| $C_{88}$ | $U_{88}$ | [6.00, 9.00] | [3.60, 8.10] | $C_{88}$ | $U_{88}$ | [9.00,10.0] | [5.40,9.00] |
| $C_{89}$ | $U_{89}$ | [7.20, 9.40] | [5.62, 8.65] | $C_{89}$ | $U_{89}$ | [6.40,8.60] | [4.99,7.91] |
| $C_{8,10}$ | $U_{8,10}$ | [6.00, 9.00] | [4.68, 8.64] | $C_{8,10}$ | $U_{8,10}$ | [6.00,9.00] | [4.68,8.64] |
| $C_{8,11}$ | $U_{8,11}$ | [2.20, 3.60] | [1.72, 3.31] | $C_{8,11}$ | $U_{8,11}$ | [6.60,9.20] | [5.15,8.46] |
| $C_{8,12}$ | $U_{8,12}$ | [4.20, 5.80] | [2.52, 5.22] | $C_{8,12}$ | $U_{8,12}$ | [7.20,9.40] | [4.32,8.46] |
| $C_{8,13}$ | $U_{8,13}$ | [6.40, 8.60] | [4.61, 8.08] | $C_{8,13}$ | $U_{8,13}$ | [6.60,9.20] | [4.75,8.65] |
| $C_{8,14}$ | $U_{8,14}$ | [6.60, 9.20] | [4.75, 8.65] | $C_{8,14}$ | $U_{8,14}$ | [6.60,9.20] | [4.75,8.65] |
| $C_{8,15}$ | $U_{8,15}$ | [7.20, 9.40] | [4.03, 7.33] | $C_{8,15}$ | $U_{8,15}$ | [6.60,9.20] | [3.70,7.18] |
| $C_{8,16}$ | $U_{8,16}$ | [2.60, 3.80] | [1.56, 3.42] | $C_{8,16}$ | $U_{8,16}$ | [7.20,9.40] | [4.32,8.46] |
| $C_{8,17}$ | $U_{8,17}$ | [6.60, 9.20] | [4.75, 8.65] | $C_{8,17}$ | $U_{8,17}$ | [6.60,9.20] | [4.75,8.65] |
| $C_{8,18}$ | $U_{8,18}$ | [1.80, 3.40] | [1.30, 3.20] | $C_{8,18}$ | $U_{8,18}$ | [6.60,9.20] | [4.75,8.65] |
| $C_{8,19}$ | $U_{8,19}$ | [8.40, 9.80] | [5.04, 8.82] | $C_{8,19}$ | $U_{8,19}$ | [7.20,9.40] | [4.32,8.46] |
| $C_{8,20}$ | $U_{8,20}$ | [6.60, 9.20] | [3.83, 7.73] | $C_{8,20}$ | $U_{8,20}$ | [6.60,9.20] | [3.83,7.73] |
| $C_{8,21}$ | $U_{8,21}$ | [1.80, 3.40] | [1.40, 3.26] | $C_{8,21}$ | $U_{8,21}$ | [6.00,9.00] | [4.68,8.64] |
| $C_{8,22}$ | $U_{8,22}$ | [4.20, 5.80] | [3.02, 5.45] | $C_{8,22}$ | $U_{8,22}$ | [6.60,9.20] | [4.75,8.65] |
| $C_{8,23}$ | $U_{8,23}$ | [6.00, 9.00] | [3.36, 7.02] | $C_{8,23}$ | $U_{8,23}$ | [7.20,9.40] | [4.03,7.33] |
| $C_{8,24}$ | $U_{8,24}$ | [6.00, 9.00] | [3.60, 8.10] | $C_{8,24}$ | $U_{8,24}$ | [6.00,9.00] | [3.60,8.10] |

Table 6.12: Grey aggregated appropriateness rating on $2^{nd}$ level attributes **(Alternative 3 & Alternative 4)**

| Grey aggregated appropriateness rating on attributes **(Alternative 3)** | | | | Grey aggregated appropriateness rating on attributes **(Alternative 4)** | | | |
|---|---|---|---|---|---|---|---|
| $2^{nd}$ level attributes ($C_{ij}$) | Rating($U_{ij}$) | Grey aggregated appropriateness rating (values) ($U_{ij}$) | Grey aggregated weighted appropriateness rating (values) ($U_{ij} \otimes w_{ij}$) | $2^{nd}$ level attributes ($C_{ij}$) | Rating($U_{ij}$) | Grey aggregated appropriateness rating (values) ($U_{ij}$) | Grey aggregated weighted appropriateness rating (values) ($U_{ij} \otimes w_{ij}$) |
| $C_{11}$ | $U_{11}$ | [1.00, 3.00] | [0.78, 2.76] | $C_{11}$ | $U_{11}$ | [7.80, 9.60] | [6.08, 8.83] |
| $C_{12}$ | $U_{12}$ | [2.60, 3.80] | [1.51, 3.19] | $C_{12}$ | $U_{12}$ | [7.80, 9.60] | [4.52, 8.06] |
| $C_{13}$ | $U_{13}$ | [2.40, 3.60] | [1.44, 3.24] | $C_{13}$ | $U_{13}$ | [6.00, 9.00] | [3.60, 8.10] |
| $C_{14}$ | $U_{14}$ | [0.80, 2.60] | [0.58, 2.44] | $C_{14}$ | $U_{14}$ | [8.40, 9.80] | [6.05, 9.21] |
| $C_{15}$ | $U_{15}$ | [3.40, 4.40] | [2.45, 4.14] | $C_{15}$ | $U_{15}$ | [5.80, 8.40] | [4.18, 7.90] |
| $C_{16}$ | $U_{16}$ | [3.60, 4.60] | [2.81, 4.23] | $C_{16}$ | $U_{16}$ | [7.60, 9.00] | [5.93, 8.28] |
| $C_{17}$ | $U_{17}$ | [4.00, 5.00] | [2.32, 4.20] | $C_{17}$ | $U_{17}$ | [5.60, 7.80] | [3.25, 6.55] |
| $C_{18}$ | $U_{18}$ | [4.20, 5.20] | [3.28, 4.99] | $C_{18}$ | $U_{18}$ | [7.20, 9.40] | [5.62, 9.02] |
| $C_{19}$ | $U_{19}$ | [3.00, 4.00] | [2.16, 3.76] | $C_{19}$ | $U_{19}$ | [5.40, 7.20] | [3.89, 6.77] |
| $C_{1,10}$ | $U_{1,10}$ | [1.00, 3.00] | [0.58, 2.52] | $C_{1,10}$ | $U_{1,10}$ | [7.80, 9.60] | [4.52, 8.06] |
| $C_{1,11}$ | $U_{1,11}$ | [2.20, 3.80] | [1.32, 3.42] | $C_{1,11}$ | $U_{1,11}$ | [5.40, 7.20] | [3.24, 6.48] |
| $C_{21}$ | $U_{21}$ | [3.40, 4.40] | [2.45, 4.14] | $C_{21}$ | $U_{21}$ | [7.20, 9.40] | [5.18, 8.84] |
| $C_{22}$ | $U_{22}$ | [1.40, 3.20] | [1.09, 3.07] | $C_{22}$ | $U_{22}$ | [7.20, 9.40] | [5.62, 9.02] |
| $C_{23}$ | $U_{23}$ | [2.60, 3.80] | [2.03, 3.50] | $C_{23}$ | $U_{23}$ | [5.60, 7.80] | [4.37, 7.18] |
| $C_{24}$ | $U_{24}$ | [2.80, 3.80] | [1.62, 3.19] | $C_{24}$ | $U_{24}$ | [5.40, 7.20] | [3.13, 6.05] |
| $C_{25}$ | $U_{25}$ | [0.80, 2.60] | [0.62, 2.50] | $C_{25}$ | $U_{25}$ | [5.60, 7.80] | [4.37, 7.49] |
| $C_{26}$ | $U_{26}$ | [3.40, 4.40] | [2.45, 4.14] | $C_{26}$ | $U_{26}$ | [7.20, 9.40] | [5.18, 8.84] |
| $C_{27}$ | $U_{27}$ | [3.60, 4.60] | [2.09, 3.86] | $C_{27}$ | $U_{27}$ | [5.40, 7.20] | [3.13, 6.05] |
| $C_{31}$ | $U_{31}$ | [4.00, 5.00] | [2.40, 4.50] | $C_{31}$ | $U_{31}$ | [6.00, 9.00] | [3.60, 8.10] |
| $C_{32}$ | $U_{32}$ | [4.20, 5.20] | [3.28, 4.78] | $C_{32}$ | $U_{32}$ | [5.60, 7.80] | [4.37, 7.18] |
| $C_{33}$ | $U_{33}$ | [2.60, 3.80] | [2.03, 3.65] | $C_{33}$ | $U_{33}$ | [7.80, 9.60] | [6.08, 9.22] |
| $C_{34}$ | $U_{34}$ | [1.40, 3.20] | [0.84, 3.65] | $C_{34}$ | $U_{34}$ | [4.40, 5.40] | [2.64, 4.86] |
| $C_{35}$ | $U_{35}$ | [2.20, 3.80] | [1.28, 3.19] | $C_{35}$ | $U_{35}$ | [6.00, 9.00] | [3.48, 7.56] |
| $C_{36}$ | $U_{36}$ | [3.40, 4.40] | [2.65, 4.22] | $C_{36}$ | $U_{36}$ | [5.60, 7.80] | [4.37, 7.49] |
| $C_{37}$ | $U_{37}$ | [1.40, 3.20] | [1.01, 3.01] | $C_{37}$ | $U_{37}$ | [5.80, 8.40] | [4.18, 7.90] |
| $C_{38}$ | $U_{38}$ | [4.20, 5.20] | [2.44, 4.37] | $C_{38}$ | $U_{38}$ | [7.80, 9.60] | [4.52, 8.06] |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $C_{41}$ | $U_{41}$ | [3.00, 4.00] | [1.80, 4.37] | $C_{41}$ | $U_{41}$ | [7.20, 9.40] | [4.32, 8.46] |
| $C_{42}$ | $U_{42}$ | [1.00, 3.00] | [0.78, 2.76] | $C_{42}$ | $U_{42}$ | [7.40, 8.40] | [5.77, 7.73] |
| $C_{43}$ | $U_{43}$ | [2.60, 4.00] | [2.03, 3.84] | $C_{43}$ | $U_{43}$ | [8.40, 9.80] | [6.55, 9.41] |
| $C_{44}$ | $U_{44}$ | [3.40, 4.40] | [2.65, 4.05] | $C_{44}$ | $U_{44}$ | [5.80, 8.40] | [4.52, 7.73] |
| $C_{45}$ | $U_{45}$ | [1.40, 3.20] | [0.81, 2.69] | $C_{45}$ | $U_{45}$ | [7.20, 9.40] | [4.18, 7.90] |
| $C_{46}$ | $U_{46}$ | [2.20, 3.60] | [1.58, 3.38] | $C_{46}$ | $U_{46}$ | [5.80, 8.40] | [4.18, 7.90] |
| $C_{51}$ | $U_{51}$ | [3.00, 4.00] | [2.16, 3.76] | $C_{51}$ | $U_{51}$ | [7.20, 9.40] | [5.18, 8.84] |
| $C_{52}$ | $U_{52}$ | [3.60, 4.60] | [2.02, 3.59] | $C_{52}$ | $U_{52}$ | [5.40, 7.20] | [3.02, 5.62] |
| $C_{53}$ | $U_{53}$ | [4.00, 5.00] | [2.40, 4.50] | $C_{53}$ | $U_{53}$ | [7.20, 9.40] | [4.32, 8.46] |
| $C_{54}$ | $U_{54}$ | [4.20, 5.20] | [3.28, 4.78] | $C_{54}$ | $U_{54}$ | [5.60, 7.80] | [4.37, 7.18] |
| $C_{55}$ | $U_{55}$ | [2.60, 3.80] | [2.03, 3.65] | $C_{55}$ | $U_{55}$ | [7.20, 9.40] | [5.62, 9.02] |
| $C_{56}$ | $U_{56}$ | [1.40, 3.20] | [1.09, 2.94] | $C_{56}$ | $U_{56}$ | [7.20, 9.40] | [5.62, 8.65] |
| $C_{57}$ | $U_{57}$ | [2.20, 3.80] | [1.28, 3.19] | $C_{57}$ | $U_{57}$ | [5.60, 7.80] | [3.25, 6.55] |
| $C_{58}$ | $U_{58}$ | [3.00, 4.20] | [2.34, 4.03] | $C_{58}$ | $U_{58}$ | [4.60, 6.00] | [3.59, 5.76] |
| $C_{59}$ | $U_{59}$ | [1.00, 3.00] | [0.72, 2.82] | $C_{59}$ | $U_{59}$ | [6.00, 9.00] | [4.32, 8.46] |
| $C_{5,10}$ | $U_{5,10}$ | [4.20, 5.20] | [2.44, 4.37] | $C_{5,10}$ | $U_{5,10}$ | [5.40, 7.20] | [3.13, 6.05] |
| $C_{5,11}$ | $U_{5,11}$ | [3.20, 4.20] | [1.92, 3.78] | $C_{5,11}$ | $U_{5,11}$ | [5.80, 8.40] | [3.48, 7.56] |
| $C_{5,12}$ | $U_{5,12}$ | [1.00, 3.00] | [0.78, 2.76] | $C_{5,12}$ | $U_{5,12}$ | [7.80, 9.60] | [6.08, 8.83] |
| $C_{5,13}$ | $U_{5,13}$ | [3.80, 4.80] | [2.96, 4.61] | $C_{5,13}$ | $U_{5,13}$ | [7.20, 9.40] | [5.62, 9.02] |
| $C_{5,14}$ | $U_{5,14}$ | [4.00, 5.00] | [3.12, 4.60] | $C_{5,14}$ | $U_{5,14}$ | [6.80, 8.20] | [5.30, 7.54] |
| $C_{5,15}$ | $U_{5,15}$ | [4.40, 5.40] | [2.55, 4.54] | $C_{5,15}$ | $U_{5,15}$ | [8.40, 9.80] | [4.87, 8.23] |
| $C_{5,16}$ | $U_{5,16}$ | [2.60, 4.60] | [2.03, 4.42] | $C_{5,16}$ | $U_{5,16}$ | [6.40, 8.60] | [4.99, 8.26] |
| $C_{5,17}$ | $U_{5,17}$ | [4.00, 5.00] | [3.12, 4.60] | $C_{5,17}$ | $U_{5,17}$ | [7.80, 9.60] | [6.08, 8.83] |
| $C_{5,18}$ | $U_{5,18}$ | [4.20, 5.20] | [2.35, 4.06] | $C_{5,18}$ | $U_{5,18}$ | [5.80, 8.40] | [3.25, 6.55] |
| $C_{5,19}$ | $U_{5,19}$ | [2.60, 3.80] | [1.56, 3.42] | $C_{5,19}$ | $U_{5,19}$ | [6.60, 9.20] | [3.96, 8.28] |
| $C_{61}$ | $U_{61}$ | [1.80, 3.40] | [1.30, 3.20] | $C_{61}$ | $U_{61}$ | [5.80, 8.40] | [4.18, 7.90] |
| $C_{62}$ | $U_{62}$ | [2.00, 3.60] | [1.56, 3.46] | $C_{62}$ | $U_{62}$ | [7.20, 9.40] | [5.62, 9.02] |
| $C_{63}$ | $U_{63}$ | [3.40, 4.40] | [2.65, 4.05] | $C_{63}$ | $U_{63}$ | [5.60, 7.80] | [4.37, 7.18] |
| $C_{64}$ | $U_{64}$ | [1.40, 3.20] | [0.81, 2.69] | $C_{64}$ | $U_{64}$ | [7.20, 9.40] | [4.18, 7.90] |
| $C_{71}$ | $U_{71}$ | [4.20, 5.20] | [3.28, 4.99] | $C_{71}$ | $U_{71}$ | [5.80, 8.40] | [4.52, 8.06] |
| $C_{72}$ | $U_{72}$ | [2.60, 3.80] | [1.87, 3.57] | $C_{72}$ | $U_{72}$ | [7.20, 9.40] | [5.18, 8.84] |
| $C_{73}$ | $U_{73}$ | [1.40, 3.20] | [0.81, 2.69] | $C_{73}$ | $U_{73}$ | [7.20, 9.40] | [4.18, 7.90] |
| $C_{74}$ | $U_{74}$ | [3.40, 4.40] | [2.04, 3.96] | $C_{74}$ | $U_{74}$ | [5.60, 7.80] | [3.36, 7.02] |
| $C_{75}$ | $U_{75}$ | [3.80, 4.80] | [2.74, 4.51] | $C_{75}$ | $U_{75}$ | [4.60, 6.00] | [3.31, 5.64] |
| $C_{76}$ | $U_{76}$ | [3.40, 4.40] | [2.65, 4.22] | $C_{76}$ | $U_{76}$ | [7.80, 9.60] | [6.08, 9.22] |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $C_{77}$ | $U_{77}$ | [4.00, 5.00] | [3.12, 4.60] | $C_{77}$ | $U_{77}$ | [5.60, 7.80] | [4.37, 7.18] |
| $C_{78}$ | $U_{78}$ | [4.20, 5.20] | [2.44, 4.37] | $C_{78}$ | $U_{78}$ | [7.20, 9.40] | [4.18, 7.90] |
| $C_{79}$ | $U_{79}$ | [2.60, 3.80] | [2.03, 3.65] | $C_{79}$ | $U_{79}$ | [5.60, 7.80] | [4.37, 7.49] |
| $C_{7,10}$ | $U_{7,10}$ | [1.40, 3.20] | [1.01, 3.01] | $C_{7,10}$ | $U_{7,10}$ | [7.20, 9.40] | [5.18, 8.84] |
| $C_{7,11}$ | $U_{7,11}$ | [2.20, 3.80] | [1.23, 2.96] | $C_{7,11}$ | $U_{7,11}$ | [7.20, 9.40] | [4.03, 7.33] |
| $C_{7,12}$ | $U_{7,12}$ | [3.40, 4.40] | [2.04, 3.96] | $C_{7,12}$ | $U_{7,12}$ | [5.60, 7.80] | [3.36, 7.02] |
| $C_{81}$ | $U_{81}$ | [1.40, 3.20] | [1.01, 3.01] | $C_{81}$ | $U_{81}$ | [4.60, 6.00] | [3.31, 5.64] |
| $C_{82}$ | $U_{82}$ | [4.00, 5.00] | [3.12, 4.80] | $C_{82}$ | $U_{82}$ | [6.00, 9.00] | [4.68, 8.64] |
| $C_{83}$ | $U_{83}$ | [2.60, 3.80] | [2.03, 3.50] | $C_{83}$ | $U_{83}$ | [5.60, 7.80] | [4.37, 7.18] |
| $C_{84}$ | $U_{84}$ | [1.40, 3.20] | [0.81, 2.69] | $C_{84}$ | $U_{84}$ | [5.80, 8.40] | [3.36, 7.06] |
| $C_{85}$ | $U_{85}$ | [2.60, 4.60] | [2.03, 4.42] | $C_{85}$ | $U_{85}$ | [7.80, 9.60] | [6.08, 9.22] |
| $C_{86}$ | $U_{86}$ | [4.00, 5.00] | [2.88, 4.70] | $C_{86}$ | $U_{86}$ | [6.60, 6.20] | [4.75, 5.83] |
| $C_{87}$ | $U_{87}$ | [4.00, 5.00] | [2.32, 4.20] | $C_{87}$ | $U_{87}$ | [6.20, 8.00] | [3.60, 6.72] |
| $C_{88}$ | $U_{88}$ | [2.60, 3.80] | [1.56, 3.42] | $C_{88}$ | $U_{88}$ | [7.80, 9.60] | [4.68, 8.64] |
| $C_{89}$ | $U_{89}$ | [1.40, 3.20] | [1.09, 2.94] | $C_{89}$ | $U_{89}$ | [6.40, 8.60] | [4.99, 7.91] |
| $C_{8,10}$ | $U_{8,10}$ | [2.20, 3.80] | [1.72, 3.65] | $C_{8,10}$ | $U_{8,10}$ | [7.20, 9.40] | [5.62, 9.02] |
| $C_{8,11}$ | $U_{8,11}$ | [3.40, 4.40] | [2.65, 4.05] | $C_{8,11}$ | $U_{8,11}$ | [8.40, 9.80] | [6.55, 9.02] |
| $C_{8,12}$ | $U_{8,12}$ | [1.00, 3.00] | [0.60, 2.70] | $C_{8,12}$ | $U_{8,12}$ | [6.60, 6.20] | [3.96, 5.58] |
| $C_{8,13}$ | $U_{8,13}$ | [2.60, 4.60] | [1.87, 4.32] | $C_{8,13}$ | $U_{8,13}$ | [7.80, 9.60] | [5.62, 9.02] |
| $C_{8,14}$ | $U_{8,14}$ | [4.00, 5.00] | [2.88, 4.70] | $C_{8,14}$ | $U_{8,14}$ | [5.60, 7.80] | [4.03, 7.33] |
| $C_{8,15}$ | $U_{8,15}$ | [4.40, 5.40] | [2.46, 4.21] | $C_{8,15}$ | $U_{8,15}$ | [7.20, 9.40] | [4.03, 7.33] |
| $C_{8,16}$ | $U_{8,16}$ | [2.60, 3.80] | [1.56, 3.42] | $C_{8,16}$ | $U_{8,16}$ | [7.20, 9.40] | [4.32, 8.46] |
| $C_{8,17}$ | $U_{8,17}$ | [1.40, 3.20] | [1.01, 3.01] | $C_{8,17}$ | $U_{8,17}$ | [6.40, 8.60] | [4.61, 8.08] |
| $C_{8,18}$ | $U_{8,18}$ | [2.20, 3.80] | [1.58, 3.57] | $C_{8,18}$ | $U_{8,18}$ | [4.80, 6.60] | [3.46, 6.20] |
| $C_{8,19}$ | $U_{8,19}$ | [3.40, 4.40] | [2.04, 3.96] | $C_{8,19}$ | $U_{8,19}$ | [6.00, 9.00] | [3.60, 8.10] |
| $C_{8,20}$ | $U_{8,20}$ | [1.40, 3.20] | [0.81, 2.69] | $C_{8,20}$ | $U_{8,20}$ | [5.80, 8.40] | [3.36, 7.06] |
| $C_{8,21}$ | $U_{8,21}$ | [4.20, 5.20] | [3.28, 4.99] | $C_{8,21}$ | $U_{8,21}$ | [6.00, 9.00] | [4.68, 8.64] |
| $C_{8,22}$ | $U_{8,22}$ | [3.20, 4.20] | [2.30, 3.95] | $C_{8,22}$ | $U_{8,22}$ | [8.40, 9.80] | [6.05, 9.21] |
| $C_{8,23}$ | $U_{8,23}$ | [1.00, 3.00] | [0.56, 2.34] | $C_{8,23}$ | $U_{8,23}$ | [8.40, 9.80] | [4.70, 7.64] |
| $C_{8,24}$ | $U_{8,24}$ | [3.40, 4.40] | [2.04, 3.96] | $C_{8,24}$ | $U_{8,24}$ | [5.40, 7.20] | [3.24, 6.48] |

Table 6.13: Grey performance rating of 1st level attributes **(Alternative 1 & Alternative 2)**

| **Alternative 1** | | | | **Alternative 2** | | | |
|---|---|---|---|---|---|---|---|
| 1st level attributes ($C_i$) | Rating($U_i$) | Grey performance rating($U_i$) | Weighted grey performance rating ($U_{ij} \otimes w_{ij}$) | 1st level attributes ($C_i$) | Rating($U_i$) | Grey performance rating($U_i$) | Weighted grey performance rating ($U_{ij} \otimes w_{ij}$) |
| $C_1$ | $U_1$ | [3.67, 8.99] | [27.3, 89.36] | $C_1$ | $U_1$ | [5.07, 11.96] | [37.72, 118.88] |
| $C_2$ | $U_2$ | [4.17, 11.12] | [18.18, 71.17] | $C_2$ | $U_2$ | [5.05, 13.13] | [22.02, 84.03] |
| $C_3$ | $U_3$ | [3.77, 9.77] | [20.43, 70.93] | $C_3$ | $U_3$ | [4.71, 11.60] | [25.53, 84.22] |
| $C_4$ | $U_4$ | [3.55, 8.55] | [15.05, 46.85] | $C_4$ | $U_4$ | [4.85, 11.20] | [20.56, 61.38 |
| $C_5$ | $U_5$ | [4.09, 9.79] | [53.66, 167.41] | $C_5$ | $U_5$ | [5.12, 11.68] | [67.17, 199.73] |
| $C_6$ | $U_6$ | [2.78, 6.77] | [7.95, 24.78] | $C_6$ | $U_6$ | [4.84, 11.06] | [13.84, 40.48] |
| $C_7$ | $U_7$ | [3.97, 10.18] | [32.55, 110.76] | $C_7$ | $U_7$ | [5.30, 12.16] | [43.46, 132.3] |
| $C_8$ | $U_8$ | [3.80, 9.61] | [62.17, 209.11] | $C_8$ | $U_8$ | [5.11, 12.27] | [83.6, 267] |

Table 6.14: Grey performance rating of 1st level attributes **(Alternative 3 & Alternative 4)**

| **Alternative 3** | | | | **Alternative 4** | | | |
|---|---|---|---|---|---|---|---|
| 1st level attributes ($C_i$) | Rating ($U_i$) | Grey performance rating($U_i$) | Weighted grey performance rating ($U_{ij} \otimes w_{ij}$) | 1st level attributes ($C_i$) | Rating($U_i$) | Grey performance rating($U_i$) | Weighted grey performance rating |
| $C_1$ | $U_1$ | [1.93, 5.23] | [14.36, 51.99] | $C_1$ | $U_1$ | [5.12, 11.73] | [38.09, 116.6] |
| $C_2$ | $U_2$ | [1.93, 5.59] | [8.41, 35.78] | $C_2$ | $U_2$ | [4.84, 12.26] | [21.1, 78.46] |
| $C_3$ | $U_3$ | [2.19, 5.65] | [11.87, 41.02] | $C_3$ | $U_3$ | [4.58, 11.14] | [24.82, 80.88] |
| $C_4$ | $U_4$ | [1.76, 4.79] | [7.46, 26.25] | $C_4$ | $U_4$ | [5.39, 11.58] | [22.85, 63.46] |
| $C_5$ | $U_5$ | [2.35, 5.67] | [30.83, 96.96] | $C_5$ | $U_5$ | [5.03, 11.58] | [65.99, 188.96] |
| $C_6$ | $U_6$ | [1.73, 4.68] | [4.95, 17.13] | $C_6$ | $U_6$ | [5.01, 11.19] | [14.33, 40.96] |
| $C_7$ | $U_7$ | [2.32, 5.67] | [19.02, 61.69] | $C_7$ | $U_7$ | [4.79, 11.27] | [39.28, 122.62] |
| $C_8$ | $U_8$ | [2.03, 5.45] | [33.21, 118.59] | $C_8$ | $U_8$ | [4.95, 11.25] | [80.98, 244.8] |

Table 6.15: Computation of grey performance important index (GPII) of 2nd level attributes **(Alternative1)**

| 2nd level attributes ($C_{ij}$) | Grey aggregated appropriateness rating (values) ($U_{ij}$) | Grey aggregated priority weight($w_{ij}$) | Grey performance important index (GPII) $[(1-w_{ij}) \otimes U_{ij}]$ | Grey possibility degree between (GPII) of two attributes under same capacity, $(0.74,3.39)_{ideal}$ $\max[(0, L^* - \max(0, \overline{G}_{ideal} - \underline{G}_i)]$ | Ranking |
|---|---|---|---|---|---|
| $C_{11}$ | [2.60, 3.80] | [0.78, 0.92] | [0.16, 0.77] | 0.01 | 2 |
| $C_{12}$ | [4.00, 5.00] | [0.58, 0.84] | [0.37, 1.76] | 0.25 | 15 |
| $C_{13}$ | [5.20, 6.60] | [0.60, 0.90] | [0.31, 2.38] | 0.35 | 24 |
| $C_{14}$ | [5.80, 8.40] | [0.72, 0.94] | [0.25, 2.21] | 0.32 | 21 |
| $C_{15}$ | [4.40, 5.40] | [0.72, 0.94] | [0.19, 1.42] | 0.18 | 11 |
| $C_{16}$ | [5.80, 8.40] | [0.78, 0.92] | [0.36, 1.70] | 0.24 | 14 |
| $C_{17}$ | [6.00, 9.00] | [0.58, 0.84] | [0.56, 3.18] | 0.46 | 30 |
| $C_{18}$ | [7.20, 9.40] | [0.78, 0.96] | [0.22, 1.98] | 0.28 | 18 |
| $C_{19}$ | [6.00, 9.00] | [0.72, 0.94] | [0.26, 2.37] | 0.34 | 23 |
| $C_{1,10}$ | [2.20, 3.60] | [0.58, 0.84] | [0.20, 1.27] | 0.14 | 7 |
| $C_{1,11}$ | [4.00, 5.00] | [0.60, 0.90] | [0.24, 1.80] | 0.25 | 15 |
| $C_{21}$ | [5.40, 7.20] | [0.72, 0.94] | [0.23, 1.90] | 0.27 | 17 |
| $C_{22}$ | [6.00, 9.00] | [0.78, 0.96] | [0.19, 1.90] | 0.27 | 17 |
| $C_{23}$ | [4.60, 6.00] | [0.78, 0.92] | [0.29, 1.21] | 0.13 | 6 |
| $C_{24}$ | [5.80, 8.40] | [0.58, 0.84] | [0.54, 2.97] | 0.44 | 28 |
| $C_{25}$ | [6.00, 9.00] | [0.78, 0.96] | [0.19, 1.90] | 0.27 | 17 |
| $C_{26}$ | [7.20, 9.40] | [0.72, 0.84] | [0.31, 2.48] | 0.36 | 35 |
| $C_{27}$ | [2.20, 3.60] | [0.58, 0.84] | [0.20, 1.27] | 0.14 | 7 |
| $C_{31}$ | [7.20, 9.40] | [0.60, 0.90] | [0.43, 3.38] | 0.47 | 31 |
| $C_{32}$ | [2.20, 3.60] | [0.78, 0.92] | [0.14, 0.73] | 0.00 | 1 |
| $C_{33}$ | [4.00, 5.00] | [0.78, 0.96] | [0.12, 1.06] | 0.09 | 5 |
| $C_{34}$ | [5.60, 7.80] | [0.60, 0.90] | [0.34, 2.81] | 0.40 | 26 |
| $C_{35}$ | [6.00, 9.00] | [0.58, 0.84] | [0.56, 3.18] | 0.46 | 30 |
| $C_{36}$ | [4.80, 6.60] | [0.78, 0.96] | [0.15, 1.39] | 0.17 | 10 |
| $C_{37}$ | [5.80, 8.40] | [0.72, 0.94] | [0.25, 2.21] | 0.32 | 21 |
| $C_{38}$ | [6.00, 9.00] | [0.58, 0.84] | [0.56, 3.18] | 0.46 | 30 |
| $C_{41}$ | [7.20, 9.40] | [0.60, 0.90] | [0.43, 3.38] | 0.47 | 31 |

| | | | | | |
|---|---|---|---|---|---|
| $C_{42}$ | [1.80, 9.40] | [0.78, 0.92] | [0.11, 0.69] | 0.00 | 1 |
| $C_{43}$ | [6.60, 9.20] | [0.78, 0.96] | [0.21, 1.94] | 0.27 | 17 |
| $C_{44}$ | [6.00, 9.00] | [0.78, 0.92] | [0.37, 1.82] | 0.26 | 16 |
| $C_{45}$ | [1.80, 3.40] | [0.58, 0.84] | [0.17, 1.20] | 0.13 | 6 |
| $C_{46}$ | [4.00, 5.00] | [0.72, 0.94] | [0.17, 1.32] | 0.15 | 8 |
| $C_{51}$ | [5.40, 7.20] | [0.72, 0.94] | [0.23, 1.90] | 0.27 | 17 |
| $C_{52}$ | [6.00, 9.00] | [0.56, 0.78] | [0.74, 3.09] | 0.47 | 31 |
| $C_{53}$ | [4.60, 6.00] | [0.60, 0.90] | [0.28, 2.16] | 0.31 | 20 |
| $C_{54}$ | [5.80, 8.40] | [0.78, 0.92] | [0.36, 1.70] | 0.24 | 14 |
| $C_{55}$ | [6.00, 9.00] | [0.78, 0.96] | [0.19, 1.90] | 0.27 | 17 |
| $C_{56}$ | [6.60, 9.20] | [0.78, 0.92] | [0.41, 1.86] | 0.27 | 17 |
| $C_{57}$ | [1.80, 3.40] | [0.58, 0.84] | [0.17, 1.20] | 0.13 | 6 |
| $C_{58}$ | [7.20, 9.40] | [0.78, 0.96] | [0.22, 1.98] | 0.28 | 18 |
| $C_{59}$ | [2.20, 3.60] | [0.72, 0.94] | [0.09, 0.95] | 0.06 | 4 |
| $C_{5,10}$ | [4.00, 5.00] | [0.58, 0.84] | [0.37, 1.76] | 0.25 | 15 |
| $C_{5,11}$ | [5.80, 8.40] | [0.60, 0.90] | [0.35, 3.02] | 0.43 | 27 |
| $C_{5,12}$ | [6.00, 9.00] | [0.78, 0.92] | [0.37, 1.82] | 0.26 | 16 |
| $C_{5,13}$ | [7.20, 9.40] | [0.78, 0.96] | [0.22, 1.98] | 0.28 | 18 |
| $C_{5,14}$ | [6.00, 9.00] | [0.78, 0.92] | [0.37, 1.82] | 0.26 | 16 |
| $C_{5,15}$ | [2.60, 3.80] | [0.58, 0.84] | [0.24, 1.34] | 0.16 | 9 |
| $C_{5,16}$ | [4.20, 5.80] | [0.78, 0.96] | [0.13, 1.23] | 0.13 | 6 |
| $C_{5,17}$ | [5.80, 8.40] | [0.78, 0.92] | [0.36, 1.70] | 0.24 | 14 |
| $C_{5,18}$ | [6.00, 9.00] | [0.56, 0.78] | [0.74, 3.09] | 0.47 | 31 |
| $C_{5,19}$ | [6.60, 9.20] | [0.60, 0.90] | [0.40, 3.31] | 0.46 | 30 |
| $C_{61}$ | [1.80, 3.40] | [0.72, 0.94] | [0.08, 0.90] | 0.05 | 3 |
| $C_{62}$ | [6.60, 9.20] | [0.78, 0.96] | [0.21, 1.94] | 0.27 | 17 |
| $C_{63}$ | [1.80, 3.40] | [0.78, 0.92] | [0.11, 0.69] | 0.00 | 1 |
| $C_{64}$ | [4.00, 5.00] | [0.58, 0.84] | [0.37, 1.76] | 0.25 | 15 |
| $C_{71}$ | [5.80, 8.40] | [0.78, 0.96] | [0.18, 1.77] | 0.24 | 14 |
| $C_{72}$ | [6.00, 9.00] | [0.72, 0.94] | [0.26, 2.37] | 0.34 | 23 |
| $C_{73}$ | [6.60, 9.20] | [0.58, 0.84] | [0.61, 3.25] | 0.47 | 31 |
| $C_{74}$ | [6.00, 9.00] | [0.60, 0.90] | [0.36, 3.24] | 0.45 | 29 |
| $C_{75}$ | [1.80, 3.40] | [0.72, 0.94] | [0.08, 0.90] | 0.05 | 3 |
| $C_{76}$ | [5.60, 7.80] | [0.78, 0.96] | [0.17, 1.65] | 0.22 | 13 |
| $C_{77}$ | [6.00, 9.00] | [0.78, 0.92] | [0.37, 1.82] | 0.26 | 16 |

| | | | | | |
|---|---|---|---|---|---|
| $C_{78}$ | [7.80, 9.60] | [0.58, 0.84] | [0.72, 3.39] | 0.50 | 33 |
| $C_{79}$ | [6.00, 9.00] | [0.78, 0.96] | [0.19, 1.90] | 0.27 | 17 |
| $C_{7,10}$ | [2.20, 3.60] | [0.72, 0.94] | [0.09, 0.95] | 0.06 | 4 |
| $C_{7,11}$ | [4.20, 5.80] | [0.56, 0.78] | [0.52, 1.99] | 0.30 | 19 |
| $C_{7,12}$ | [5.80, 5.40] | [0.60, 0.90] | [0.35, 3.02] | 0.43 | 27 |
| $C_{81}$ | [6.60, 9.20] | [0.72, 0.94] | [0.29, 2.42] | 0.35 | 24 |
| $C_{82}$ | [6.60, 9.20] | [0.78, 0.96] | [0.21, 1.94] | 0.27 | 17 |
| $C_{83}$ | [2.60, 3.80] | [0.78, 0.92] | [0.16, 0.77] | 0.01 | 2 |
| $C_{84}$ | [6.60, 9.20] | [0.58, 0.84] | [0.61, 3.25] | 0.47 | 31 |
| $C_{85}$ | [1.80, 3.40] | [0.78, 0.96] | [0.06, 0.72] | 0.00 | 1 |
| $C_{86}$ | [3.80, 4.80] | [0.72, 0.94] | [0.16, 1.26] | 0.14 | 7 |
| $C_{87}$ | [5.80, 8.40] | [0.58, 0.84] | [0.54, 2.97] | 0.44 | 28 |
| $C_{88}$ | [6.00, 9.00] | [0.60, 0.90] | [0.36, 3.24] | 0.45 | 29 |
| $C_{89}$ | [7.20, 9.40] | [0.78, 0.92] | [0.45, 1.90] | 0.28 | 18 |
| $C_{8,10}$ | [6.00, 9.00] | [0.78, 0.96] | [0.19, 1.90] | 0.27 | 17 |
| $C_{8,11}$ | [2.20, 3.60] | [0.78, 0.92] | [0.14, 0.73] | 0.00 | 1 |
| $C_{8,12}$ | [4.20, 5.80] | [0.60, 0.90] | [0.25, 2.09] | 0.30 | 19 |
| $C_{8,13}$ | [6.40, 8.60] | [0.72, 0.94] | [0.28, 2.26] | 0.33 | 22 |
| $C_{8,14}$ | [6.60, 9.20] | [0.72, 0.94] | [0.29, 2.42] | 0.35 | 24 |
| $C_{8,15}$ | [7.20, 9.40] | [0.56, 0.78] | [0.89, 3.23] | 0.50 | 33 |
| $C_{8,16}$ | [2.60, 3.80] | [0.60, 0.90] | [0.16, 1.37] | 0.16 | 9 |
| $C_{8,17}$ | [6.60, 9.20] | [0.72, 0.94] | [0.29, 2.42] | 0.35 | 24 |
| $C_{8,18}$ | [1.80, 3.40] | [0.72, 0.94] | [0.08, 0.90] | 0.05 | 3 |
| $C_{8,19}$ | [8.40, 9.80] | [0.60, 0.90] | [0.50, 3.53] | 0.49 | 32 |
| $C_{8,20}$ | [6.60, 9.20] | [0.58, 0.84] | [0.61, 3.53] | 0.47 | 31 |
| $C_{8,21}$ | [1.80, 3.40] | [0.78, 0.96] | [0.06, 0.72] | 0.00 | 1 |
| $C_{8,22}$ | [4.20, 5.80] | [0.72, 0.94] | [0.18, 1.53] | 0.20 | 12 |
| $C_{8,23}$ | [6.00, 9.00] | [0.56, 0.78] | [0.74, 3.09] | 0.47 | 31 |
| $C_{8,24}$ | [6.00, 9.00] | [0.60, 0.90] | [0.36, 3.24] | 0.45 | 29 |

Table 6.16: Computation of grey performance important index (GPII) of $2^{nd}$ level attributes **(Alternative 2)**

| $2^{nd}$ level attributes ($C_{ij}$) | Grey aggregated appropriateness rating (values) ($U_{ij}$) | Grey aggregated priority weight($w_{ij}$) | Grey performance important index (GPII) $[(1-w_{ij}) \otimes U_{ij}]$ | Grey possibility degree between (GPII) of two attributes under same capacity, $(1.58,4.14)_{ideal}$ $\max[(0, L^* - \max(0, \overline{G}_{ideal} - \underline{G}_i)]$ | Ranking |
|---|---|---|---|---|---|
| $C_{11}$ | [8.40, 9.80] | [0.78, 0.92] | [0.67, 2.16] | 0.14 | 11 |
| $C_{12}$ | [6.60, 9.20] | [0.58, 0.84] | [1.06, 3.86] | 0.43 | 28 |
| $C_{13}$ | [5.80, 8.40] | [0.60, 0.90] | [0.58, 3.36] | 0.33 | 22 |
| $C_{14}$ | [6.60, 9.20] | [0.72, 0.94] | [0.40, 2.58] | 0.21 | 15 |
| $C_{15}$ | [9.00, 10.0] | [0.72, 0.94] | [0.54, 2.80] | 0.25 | 20 |
| $C_{16}$ | [7.80, 9.60] | [0.78, 0.92] | [0.62, 2.11] | 0.13 | 10 |
| $C_{17}$ | [6.00, 9.00] | [0.58, 0.84] | [0.96, 3.78] | 0.41 | 26 |
| $C_{18}$ | [4.60, 6.00] | [0.78, 0.96] | [0.18, 1.32] | 0.00 | 1 |
| $C_{19}$ | [6.00, 9.00] | [0.72, 0.94] | [0.36, 2.52] | 0.20 | 14 |
| $C_{1,10}$ | [6.00, 9.00] | [0.58, 0.84] | [0.96, 3.78] | 0.41 | 26 |
| $C_{1,11}$ | [7.20, 9.40] | [0.60, 0.90] | [0.72, 3.76] | 0.39 | 25 |
| $C_{21}$ | [7.20,9.40] | [0.72, 0.94] | [0.43, 2.63] | 0.22 | 17 |
| $C_{22}$ | [5.60, 7.80] | [0.78, 0.96] | [0.22, 1.72] | 0.03 | 2 |
| $C_{23}$ | [7.20, 9.40] | [0.78, 0.92] | [0.58, 2.07] | 0.12 | 9 |
| $C_{24}$ | [5.80, 8.40] | [0.58, 0.84] | [0.93, 3.53] | 0.38 | 24 |
| $C_{25}$ | [7.20, 9.40] | [0.78, 0.96] | [0.29, 2.07] | 0.11 | 8 |
| $C_{26}$ | [6.00, 9.00] | [0.72, 0.84] | [0.36, 2.52] | 0.20 | 14 |
| $C_{27}$ | [6.60, 9.20] | [0.58, 0.84] | [1.06, 3.86] | 0.43 | 28 |
| $C_{31}$ | [5.00, 6.80] | [0.60, 0.90] | [0.50, 2.72] | 0.24 | 19 |
| $C_{32}$ | [6.60, 9.20] | [0.78, 0.92] | [0.53, 2.02] | 0.11 | 8 |
| $C_{33}$ | [6.00, 9.00] | [0.78, 0.96] | [0.24, 1.98] | 0.09 | 6 |
| $C_{34}$ | [7.20, 9.40] | [0.60, 0.90] | [0.72, 3.76] | 0.39 | 25 |
| $C_{35}$ | [7.20, 9.40] | [0.58, 0.84] | [1.15, 3.95] | 0.44 | 29 |
| $C_{36}$ | [6.20, 8.00] | [0.78, 0.96] | [0.25, 1.76] | 0.04 | 3 |
| $C_{37}$ | [5.80, 8.40] | [0.72, 0.94] | [0.35, 2.35] | 0.17 | 12 |
| $C_{38}$ | [6.60,9.20] | [0.58, 0.84] | [1.06, 3.86] | 0.43 | 28 |
| $C_{41}$ | [8.40,9.80] | [0.60, 0.90] | [0.84, 3.92] | 0.41 | 26 |

| | | | | | |
|---|---|---|---|---|---|
| $C_{42}$ | [7.20,9.40] | [0.78, 0.92] | [0.58, 2.07] | 0.12 | 9 |
| $C_{43}$ | [6.00,9.00] | [0.78, 0.96] | [0.24, 1.98] | 0.09 | 6 |
| $C_{44}$ | [4.40,5.80] | [0.78, 0.92] | [0.35, 1.28] | 0.00 | 1 |
| $C_{45}$ | [6.00,9.00] | [0.58, 0.84] | [0.96, 3.78] | 0.41 | 26 |
| $C_{46}$ | [6.00,9.00] | [0.72, 0.94] | [0.36, 2.52] | 0.20 | 14 |
| $C_{51}$ | [6.60,9.20] | [0.72, 0.94] | [0.40, 2.58] | 0.21 | 16 |
| $C_{52}$ | [5.80,8.40] | [0.56, 0.78] | [1.28, 3.70] | 0.42 | 27 |
| $C_{53}$ | [7.20,9.40] | [0.60, 0.90] | [0.72, 3.76] | 0.39 | 25 |
| $C_{54}$ | [6.00,9.00] | [0.78, 0.92] | [0.48, 1.98] | 0.10 | 7 |
| $C_{55}$ | [6.60,9.20] | [0.78, 0.96] | [0.26, 2.02] | 0.10 | 7 |
| $C_{56}$ | [5.00,6.80] | [0.78, 0.92] | [0.40, 1.50] | 0.00 | 1 |
| $C_{57}$ | [7.20,9.40] | [0.58, 0.84] | [1.15, 3.95] | 0.44 | 29 |
| $C_{58}$ | [6.60,9.20] | [0.78, 0.96] | [0.26, 2.02] | 0.10 | 7 |
| $C_{59}$ | [7.80,9.60] | [0.72, 0.94] | [0.47, 2.69] | 0.23 | 18 |
| $C_{5,10}$ | [7.20,9.40] | [0.58, 0.84] | [1.15, 3.95] | 0.44 | 29 |
| $C_{5,11}$ | [6.20,8.00] | [0.60, 0.90] | [0.62, 3.20] | 0.31 | 21 |
| $C_{5,12}$ | [5.80,8.40] | [0.78, 0.92] | [0.46, 1.85] | 0.07 | 4 |
| $C_{5,13}$ | [6.60,9.20] | [0.78, 0.96] | [0.26, 2.02] | 0.10 | 7 |
| $C_{5,14}$ | [7.80,9.60] | [0.78, 0.92] | [0.62, 2.11] | 0.13 | 10 |
| $C_{5,15}$ | [6.60,9.20] | [0.58, 0.84] | [1.06, 3.86] | 0.43 | 28 |
| $C_{5,16}$ | [6.40,8.60] | [0.78, 0.96] | [0.26, 1.89] | 0.07 | 4 |
| $C_{5,17}$ | [8.40,9.80] | [0.78, 0.92] | [0.67, 2.16] | 0.14 | 11 |
| $C_{5,18}$ | [5.80,8.40] | [0.56, 0.78] | [1.28, 3.70] | 0.42 | 27 |
| $C_{5,19}$ | [7.20,9.40] | [0.60, 0.90] | [0.72, 3.70] | 0.39 | 25 |
| $C_{61}$ | [6.00,9.00] | [0.72, 0.94] | [0.36, 2.52] | 0.20 | 14 |
| $C_{62}$ | [6.60,9.20] | [0.78, 0.96] | [0.26, 2.02] | 0.10 | 7 |
| $C_{63}$ | [5.20,7.00] | [0.78, 0.92] | [0.42, 1.54] | 0.00 | 1 |
| $C_{64}$ | [7.20,9.40] | [0.58, 0.84] | [1.15, 3.95] | 0.44 | 29 |
| $C_{71}$ | [6.60,9.20] | [0.78, 0.96] | [0.26, 2.02] | 0.10 | 7 |
| $C_{72}$ | [8.40,9.80] | [0.72, 0.94] | [0.50, 2.74] | 0.24 | 19 |
| $C_{73}$ | [7.80,9.60] | [0.58, 0.84] | [1.25, 4.03] | 0.46 | 30 |
| $C_{74}$ | [6.80,8.20] | [0.60, 0.90] | [0.68, 3.28] | 0.33 | 22 |
| $C_{75}$ | [6.40,8.60] | [0.72, 0.94] | [0.38, 2.41] | 0.18 | 13 |
| $C_{76}$ | [6.60,9.20] | [0.78, 0.96] | [0.26, 2.02] | 0.10 | 7 |
| $C_{77}$ | [7.80,9.60] | [0.78, 0.92] | [0.62, 2.11] | 0.13 | 10 |

| | | | | | |
|---|---|---|---|---|---|
| $C_{78}$ | [7.20,9.40] | [0.58, 0.84] | [1.15, 3.95] | 0.44 | 29 |
| $C_{79}$ | [7.20,9.40] | [0.78, 0.96] | [0.29, 2.07] | 0.11 | 8 |
| $C_{7,10}$ | [5.80,8.40] | [0.72, 0.94] | [0.35, 2.35] | 0.17 | 12 |
| $C_{7,11}$ | [6.60,9.20] | [0.56, 0.78] | [1.45, 4.05] | 0.48 | 31 |
| $C_{7,12}$ | [7.20,9.40] | [0.60, 0.90] | [0.72, 3.76] | 0.39 | 25 |
| $C_{81}$ | [6.60,9.20] | [0.72, 0.94] | [0.40, 2.58] | 0.21 | 15 |
| $C_{82}$ | [6.40,8.60] | [0.78, 0.96] | [0.26, 1.89] | 0.07 | 4 |
| $C_{83}$ | [8.40,9.80] | [0.78, 0.92] | [0.67, 2.16] | 0.14 | 11 |
| $C_{84}$ | [6.00,9.00] | [0.58, 0.84] | [0.96, 3.78] | 0.41 | 26 |
| $C_{85}$ | [7.20,9.40] | [0.78, 0.96] | [0.29, 2.07] | 0.11 | 8 |
| $C_{86}$ | [6.60,9.20] | [0.72, 0.94] | [0.40, 2.58] | 0.21 | 15 |
| $C_{87}$ | [7.20,9.40] | [0.58, 0.84] | [1.15, 3.95] | 0.44 | 29 |
| $C_{88}$ | [9.00,10.0] | [0.60, 0.90] | [0.90, 4.00] | 0.43 | 28 |
| $C_{89}$ | [6.40,8.60] | [0.78, 0.92] | [0.51, 1.89] | 0.08 | 5 |
| $C_{8,10}$ | [6.00,9.00] | [0.78, 0.96] | [0.24, 1.98] | 0.09 | 6 |
| $C_{8,11}$ | [6.60,9.20] | [0.78, 0.92] | [0.53, 2.02] | 0.11 | 8 |
| $C_{8,12}$ | [7.20,9.40] | [0.60, 0.90] | [0.72, 3.76] | 0.39 | 25 |
| $C_{8,13}$ | [6.60,9.20] | [0.72, 0.94] | [0.40, 2.58] | 0.21 | 15 |
| $C_{8,14}$ | [6.60,9.20] | [0.72, 0.94] | [0.40, 2.58] | 0.21 | 15 |
| $C_{8,15}$ | [6.60,9.20] | [0.56, 0.78] | [1.45, 4.05] | 0.48 | 31 |
| $C_{8,16}$ | [7.20,9.40] | [0.60, 0.90] | [0.72, 3.76] | 0.39 | 25 |
| $C_{8,17}$ | [6.60,9.20] | [0.72, 0.94] | [0.40, 2.58] | 0.21 | 15 |
| $C_{8,18}$ | [6.60,9.20] | [0.72, 0.94] | [0.40, 2.58] | 0.21 | 15 |
| $C_{8,19}$ | [7.20,9.40] | [0.60, 0.90] | [0.72, 3.76] | 0.39 | 25 |
| $C_{8,20}$ | [6.60,9.20] | [0.58, 0.84] | [1.06, 3.86] | 0.43 | 28 |
| $C_{8,21}$ | [6.00,9.00] | [0.78, 0.96] | [0.24, 1.98] | 0.09 | 6 |
| $C_{8,22}$ | [6.60,9.20] | [0.72, 0.94] | [0.40, 2.58] | 0.21 | 1 |
| $C_{8,23}$ | [7.20,9.40] | [0.56, 0.78] | [1.58, 4.14] | 0.50 | 32 |
| $C_{8,24}$ | [6.00,9.00] | [0.60, 0.90] | [0.60, 3.60] | 0.36 | 23 |

Table 6.17: Computation of grey performance important index (GPII) of 2nd level attributes **(Alternative 3)**

| 2nd level attributes ($C_{ij}$) | Grey aggregated appropriateness rating (values) ($U_{ij}$) | Grey aggregated priority weight($w_{ij}$) | Grey performance important index (GPII) $[(1-w_{ij})\otimes U_{ij}]$ | Grey possibility degree between (GPII) of two attributes under same capacity, $(0.97,2.38)_{ideal}$ $\max[(0, L^* - \max(0, \overline{G}_{ideal} - \underline{G}_i)]$ | Ranking |
|---|---|---|---|---|---|
| $C_{11}$ | [1.00, 3.00] | [0.78, 0.92] | [0.08, 0.66] | 0.00 | 1 |
| $C_{12}$ | [2.60, 3.80] | [0.58, 0.84] | [0.42, 1.60] | 0.24 | 18 |
| $C_{13}$ | [2.40, 3.60] | [0.60, 0.90] | [0.24, 1.44] | 0.18 | 14 |
| $C_{14}$ | [0.80, 2.60] | [0.72, 0.94] | [0.05, 0.73] | 0.00 | 1 |
| $C_{15}$ | [3.40, 4.40] | [0.72, 0.94] | [0.20, 1.23] | 0.11 | 8 |
| $C_{16}$ | [3.60, 4.60] | [0.78, 0.92] | [0.29, 1.01] | 0.02 | 2 |
| $C_{17}$ | [4.00, 5.00] | [0.58, 0.84] | [0.64, 2.10] | 0.40 | 25 |
| $C_{18}$ | [4.20, 5.20] | [0.78, 0.96] | [0.17, 1.14] | 0.07 | 5 |
| $C_{19}$ | [3.00, 4.00] | [0.72, 0.94] | [0.18, 1.12] | 0.07 | 5 |
| $C_{1,10}$ | [1.00, 3.00] | [0.58, 0.84] | [0.16, 1.26] | 0.12 | 9 |
| $C_{1,11}$ | [2.20, 3.80] | [0.60, 0.90] | [0.22, 1.52] | 0.20 | 15 |
| $C_{21}$ | [3.40, 4.40] | [0.72, 0.94] | [0.20, 1.23] | 0.11 | 8 |
| $C_{22}$ | [1.40, 3.20] | [0.78, 0.96] | [0.06, 0.70] | 0.00 | 1 |
| $C_{23}$ | [2.60, 3.80] | [0.78, 0.92] | [0.21, 0.84] | 0.00 | 1 |
| $C_{24}$ | [2.80, 3.80] | [0.58, 0.84] | [0.45, 1.60] | 0.25 | 19 |
| $C_{25}$ | [0.80, 2.60] | [0.78, 0.96] | [0.03, 0.57] | 0.00 | 1 |
| $C_{26}$ | [3.40, 4.40] | [0.72, 0.84] | [0.20, 1.23] | 0.11 | 8 |
| $C_{27}$ | [3.60, 4.60] | [0.58, 0.84] | [0.58, 1.93] | 0.35 | 24 |
| $C_{31}$ | [4.00, 5.00] | [0.60, 0.90] | [0.40, 2.00] | 0.34 | 23 |
| $C_{32}$ | [4.20, 5.20] | [0.78, 0.92] | [0.34, 1.14] | 0.08 | 6 |
| $C_{33}$ | [2.60, 3.80] | [0.78, 0.96] | [0.10, 0.84] | 0.00 | 1 |
| $C_{34}$ | [1.40, 3.20] | [0.60, 0.90] | [0.14, 1.28] | 0.12 | 9 |
| $C_{35}$ | [2.20, 3.80] | [0.58, 0.84] | [0.35, 1.60] | 0.24 | 18 |
| $C_{36}$ | [3.40, 4.40] | [0.78, 0.96] | [0.14, 0.97] | 0.00 | 1 |
| $C_{37}$ | [1.40, 3.20] | [0.72, 0.94] | [0.08, 0.90] | 0.00 | 1 |
| $C_{38}$ | [4.20, 5.20] | [0.58, 0.84] | [0.67, 2.18] | 0.42 | 26 |
| $C_{41}$ | [3.00, 4.00] | [0.60, 0.90] | [0.30, 1.60] | 0.23 | 17 |
| $C_{42}$ | [1.00, 3.00] | [0.78, 0.92] | [0.08, 0.66] | 0.00 | 1 |

| | | | | | |
|---|---|---|---|---|---|
| $C_{43}$ | [2.60, 4.00] | [0.78, 0.96] | [0.10, 0.88] | 0.00 | 1 |
| $C_{44}$ | [3.40, 4.40] | [0.78, 0.92] | [0.27, 0.97] | 0.00 | 1 |
| $C_{45}$ | [1.40, 3.20] | [0.58, 0.84] | [0.22, 1.34] | 0.15 | 12 |
| $C_{46}$ | [2.20, 3.60] | [0.72, 0.94] | [0.13, 1.01] | 0.02 | 2 |
| $C_{51}$ | [3.00, 4.00] | [0.72, 0.94] | [0.18, 1.12] | 0.07 | 5 |
| $C_{52}$ | [3.60, 4.60] | [0.56, 0.78] | [0.79, 2.02] | 0.40 | 25 |
| $C_{53}$ | [4.00, 5.00] | [0.60, 0.90] | [0.40, 2.00] | 0.34 | 23 |
| $C_{54}$ | [4.20, 5.20] | [0.78, 0.92] | [0.34, 1.14] | 0.08 | 6 |
| $C_{55}$ | [2.60, 3.80] | [0.78, 0.96] | [0.10, 0.84] | 0.00 | 1 |
| $C_{56}$ | [1.40, 3.20] | [0.78, 0.92] | [0.11, 0.70] | 0.00 | 1 |
| $C_{57}$ | [2.20, 3.80] | [0.58, 0.84] | [0.35, 1.60] | 0.24 | 18 |
| $C_{58}$ | [3.00, 4.20] | [0.78, 0.96] | [0.12, 0.92] | 0.00 | 1 |
| $C_{59}$ | [1.00, 3.00] | [0.72, 0.94] | [0.06, 0.84] | 0.00 | 1 |
| $C_{5,10}$ | [4.20, 5.20] | [0.58, 0.84] | [0.67, 2.18] | 0.42 | 26 |
| $C_{5,11}$ | [3.20, 4.20] | [0.60, 0.90] | [0.32, 1.68] | 0.26 | 20 |
| $C_{5,12}$ | [1.00, 3.00] | [0.78, 0.92] | [0.08, 0.66] | 0.00 | 1 |
| $C_{5,13}$ | [3.80, 4.80] | [0.78, 0.96] | [0.15, 1.06] | 0.04 | 3 |
| $C_{5,14}$ | [4.00, 5.00] | [0.78, 0.92] | [0.32, 1.10] | 0.06 | 4 |
| $C_{5,15}$ | [4.40, 5.40] | [0.58, 0.84] | [0.70, 2.27] | 0.44 | 27 |
| $C_{5,16}$ | [2.60, 4.60] | [0.78, 0.96] | [0.10, 1.01] | 0.02 | 2 |
| $C_{5,17}$ | [4.00, 5.00] | [0.78, 0.92] | [0.32, 1.10] | 0.06 | 4 |
| $C_{5,18}$ | [4.20, 5.20] | [0.56, 0.78] | [0.92, 2.29] | 0.48 | 28 |
| $C_{5,19}$ | [2.60, 3.80] | [0.60, 0.90] | [0.26, 1.52] | 0.21 | 16 |
| $C_{61}$ | [1.80, 3.40] | [0.72, 0.94] | [0.11, 0.95] | 0.00 | 1 |
| $C_{62}$ | [2.00, 3.60] | [0.78, 0.96] | [0.08, 0.79] | 0.00 | 1 |
| $C_{63}$ | [3.40, 4.40] | [0.78, 0.92] | [0.27, 0.97] | 0.00 | 1 |
| $C_{64}$ | [1.40, 3.20] | [0.58, 0.84] | [0.22, 1.34] | 0.15 | 12 |
| $C_{71}$ | [4.20, 5.20] | [0.78, 0.96] | [0.17, 1.14] | 0.07 | 5 |
| $C_{72}$ | [2.60, 3.80] | [0.72, 0.94] | [0.16, 1.06] | 0.04 | 3 |
| $C_{73}$ | [1.40, 3.20] | [0.58, 0.84] | [0.22, 1.34] | 0.15 | 12 |
| $C_{74}$ | [3.40, 4.40] | [0.60, 0.90] | [0.34, 1.76] | 0.28 | 22 |
| $C_{75}$ | [3.80, 4.80] | [0.72, 0.94] | [0.23, 1.34] | 0.15 | 12 |
| $C_{76}$ | [3.40, 4.40] | [0.78, 0.96] | [0.14, 0.97] | 0.00 | 1 |
| $C_{77}$ | [4.00, 5.00] | [0.78, 0.92] | [0.32, 1.10] | 0.06 | 4 |
| $C_{78}$ | [4.20, 5.20] | [0.58, 0.84] | [0.67, 2.18] | 0.42 | 26 |

| | | | | | |
|---|---|---|---|---|---|
| $C_{79}$ | [2.60, 3.80] | [0.78, 0.96] | [0.10, 0.84] | 0.00 | 1 |
| $C_{7,10}$ | [1.40, 3.20] | [0.72, 0.94] | [0.08, 0.90] | 0.00 | 1 |
| $C_{7,11}$ | [2.20, 3.80] | [0.56, 0.78] | [0.48, 1.67] | 0.27 | 21 |
| $C_{7,12}$ | [3.40, 4.40] | [0.60, 0.90] | [0.34, 1.76] | 0.28 | 22 |
| $C_{81}$ | [1.40, 3.20] | [0.72, 0.94] | [0.08, 0.90] | 0.00 | 1 |
| $C_{82}$ | [4.00, 5.00] | [0.78, 0.96] | [0.16, 1.10] | 0.06 | 4 |
| $C_{83}$ | [2.60, 3.80] | [0.78, 0.92] | [0.21, 0.84] | 0.00 | 1 |
| $C_{84}$ | [1.40, 3.20] | [0.58, 0.84] | [0.22, 1.34] | 0.15 | 12 |
| $C_{85}$ | [2.60, 4.60] | [0.78, 0.96] | [0.10, 1.01] | 0.02 | 2 |
| $C_{86}$ | [4.00, 5.00] | [0.72, 0.94] | [0.24, 1.40] | 0.17 | 13 |
| $C_{87}$ | [4.00, 5.00] | [0.58, 0.84] | [0.64, 2.10] | 0.40 | 25 |
| $C_{88}$ | [2.60, 3.80] | [0.60, 0.90] | [0.26, 1.52] | 0.21 | 16 |
| $C_{89}$ | [1.40, 3.20] | [0.78, 0.92] | [0.11, 0.70] | 0.00 | 1 |
| $C_{8,10}$ | [2.20, 3.80] | [0.78, 0.96] | [0.09, 0.84] | 0.00 | 1 |
| $C_{8,11}$ | [3.40, 4.40] | [0.78, 0.92] | [0.27, 0.97] | 0.00 | 1 |
| $C_{8,12}$ | [1.00, 3.00] | [0.60, 0.90] | [0.10, 1.20] | 0.09 | 7 |
| $C_{8,13}$ | [2.60, 4.60] | [0.72, 0.94] | [0.16, 1.29] | 0.13 | 10 |
| $C_{8,14}$ | [4.00, 5.00] | [0.72, 0.94] | [0.24, 1.40] | 0.17 | 13 |
| $C_{8,15}$ | [4.40, 5.40] | [0.56, 0.78] | [0.97, 2.38] | 0.50 | 29 |
| $C_{8,16}$ | [2.60, 3.80] | [0.60, 0.90] | [0.26, 1.52] | 0.21 | 16 |
| $C_{8,17}$ | [1.40, 3.20] | [0.72, 0.94] | [0.08, 0.90] | 0.00 | 1 |
| $C_{8,18}$ | [2.20, 3.80] | [0.72, 0.94] | [0.13, 1.06] | 0.04 | 3 |
| $C_{8,19}$ | [3.40, 4.40] | [0.60, 0.90] | [0.34, 1.76] | 0.28 | 22 |
| $C_{8,20}$ | [1.40, 3.20] | [0.58, 0.84] | [0.22, 1.34] | 0.15 | 12 |
| $C_{8,21}$ | [4.20, 5.20] | [0.78, 0.96] | [0.17, 1.14] | 0.07 | 5 |
| $C_{8,22}$ | [3.20, 4.20] | [0.72, 0.94] | [0.19, 1.18] | 0.09 | 7 |
| $C_{8,23}$ | [1.00, 3.00] | [0.56, 0.78] | [0.22, 1.32] | 0.14 | 11 |
| $C_{8,24}$ | [3.40, 4.40] | [0.60, 0.90] | [0.34, 1.76] | 0.28 | 22 |

Table 6.18: Computation of grey performance important index (GPII) of 2nd level attributes **(Alternative 4)**

| 2nd level attributes ($C_{ij}$) | Grey aggregated appropriateness rating (values) ($U_{ij}$) | Grey aggregated priority weight($w_{ij}$) | Grey performance important index (GPII) $[(1 - w_{ij}) \otimes U_{ij}]$ | Grey possibility degree between (GPII) of two attributes under same capacity, $(1.85, 4.31)_{ideal}$ $\max[(0, L^* - \max(0, \overline{G}_{ideal} - \underline{G}_i)]$ | Ranking |
|---|---|---|---|---|---|
| $C_{11}$ | [7.80, 9.60] | [0.78, 0.92] | [0.62, 2.11] | 0.07 | 7 |
| $C_{12}$ | [7.80, 9.60] | [0.58, 0.84] | [1.25, 4.03] | 0.42 | 27 |
| $C_{13}$ | [6.00, 9.00] | [0.60, 0.90] | [0.60, 3.60] | 0.32 | 20 |
| $C_{14}$ | [8.40, 9.80] | [0.72, 0.94] | [0.50, 2.74] | 0.19 | 14 |
| $C_{15}$ | [5.80, 8.40] | [0.72, 0.94] | [0.35, 2.35] | 0.11 | 9 |
| $C_{16}$ | [7.60, 9.00] | [0.78, 0.92] | [0.61, 1.98] | 0.04 | 4 |
| $C_{17}$ | [5.60, 7.80] | [0.58, 0.84] | [0.90, 3.28] | 0.30 | 18 |
| $C_{18}$ | [7.20, 9.40] | [0.78, 0.96] | [0.29, 2.07] | 0.05 | 5 |
| $C_{19}$ | [5.40, 7.20] | [0.72, 0.94] | [0.32, 2.02] | 0.04 | 4 |
| $C_{1,10}$ | [7.80, 9.60] | [0.58, 0.84] | [1.25, 4.03] | 0.42 | 27 |
| $C_{1,11}$ | [5.40, 7.20] | [0.60, 0.90] | [0.54, 2.88] | 0.22 | 15 |
| $C_{21}$ | [7.20, 9.40] | [0.72, 0.94] | [0.43, 2.63] | 0.17 | 12 |
| $C_{22}$ | [7.20, 9.40] | [0.78, 0.96] | [0.29, 2.07] | 0.05 | 5 |
| $C_{23}$ | [5.60, 7.80] | [0.78, 0.92] | [0.45, 1.72] | 0.00 | 1 |
| $C_{24}$ | [5.40, 7.20] | [0.58, 0.84] | [0.86, 3.02] | 0.25 | 16 |
| $C_{25}$ | [5.60, 7.80] | [0.78, 0.96] | [0.22, 1.72] | 0.00 | 1 |
| $C_{26}$ | [7.20, 9.40] | [0.72, 0.84] | [0.43, 2.63] | 0.17 | 12 |
| $C_{27}$ | [5.40, 7.20] | [0.58, 0.84] | [0.86, 3.02] | 0.25 | 16 |
| $C_{31}$ | [6.00, 9.00] | [0.60, 0.90] | [0.60, 3.60] | 0.32 | 20 |
| $C_{32}$ | [5.60, 7.80] | [0.78, 0.92] | [0.45, 1.72] | 0.00 | 1 |
| $C_{33}$ | [7.80, 9.60] | [0.78, 0.96] | [0.31, 2.11] | 0.06 | 6 |
| $C_{34}$ | [4.40, 5.40] | [0.60, 0.90] | [0.44, 2.16] | 0.08 | 8 |
| $C_{35}$ | [6.00, 9.00] | [0.58, 0.84] | [0.96, 3.78] | 0.37 | 24 |
| $C_{36}$ | [5.60, 7.80] | [0.78, 0.96] | [0.22, 1.72] | 0.00 | 1 |
| $C_{37}$ | [5.80, 8.40] | [0.72, 0.94] | [0.35, 2.35] | 0.11 | 9 |
| $C_{38}$ | [7.80, 9.60] | [0.58, 0.84] | [1.25, 4.03] | 0.42 | 27 |
| $C_{41}$ | [7.20, 9.40] | [0.60, 0.90] | [0.72, 3.76] | 0.35 | 22 |
| $C_{42}$ | [7.40, 8.40] | [0.78, 0.92] | [0.59, 1.85] | 0.00 | 1 |

| | | | | | |
|---|---|---|---|---|---|
| $C_{43}$ | [8.40, 9.80] | [0.78, 0.96] | [0.34, 2.16] | 0.07 | 7 |
| $C_{44}$ | [5.80, 8.40] | [0.78, 0.92] | [0.46, 1.85] | 0.00 | 1 |
| $C_{45}$ | [7.20, 9.40] | [0.58, 0.84] | [1.15, 3.95] | 0.40 | 26 |
| $C_{46}$ | [5.80, 8.40] | [0.72, 0.94] | [0.35, 2.35] | 0.11 | 9 |
| $C_{51}$ | [7.20, 9.40] | [0.72, 0.94] | [0.43, 2.63] | 0.17 | 12 |
| $C_{52}$ | [5.40, 7.20] | [0.56, 0.78] | [1.19, 3.17] | 0.30 | 18 |
| $C_{53}$ | [7.20, 9.40] | [0.60, 0.90] | [0.72, 3.76] | 0.35 | 22 |
| $C_{54}$ | [5.60, 7.80] | [0.78, 0.92] | [0.45, 1.72] | 0.00 | 1 |
| $C_{55}$ | [7.20, 9.40] | [0.78, 0.96] | [0.29, 2.07] | 0.05 | 5 |
| $C_{56}$ | [7.20, 9.40] | [0.78, 0.92] | [0.58, 2.07] | 0.06 | 6 |
| $C_{57}$ | [5.60, 7.80] | [0.58, 0.84] | [0.90, 3.28] | 0.30 | 18 |
| $C_{58}$ | [4.60, 6.00] | [0.78, 0.96] | [0.18, 1.32] | 0.00 | 1 |
| $C_{59}$ | [6.00, 9.00] | [0.72, 0.94] | [0.36, 2.52] | 0.15 | 11 |
| $C_{5,10}$ | [5.40, 7.20] | [0.58, 0.84] | [0.86, 3.02] | 0.25 | 16 |
| $C_{5,11}$ | [5.80, 8.40] | [0.60, 0.90] | [0.58, 3.36] | 0.29 | 17 |
| $C_{5,12}$ | [7.80, 9.60] | [0.78, 0.92] | [0.62, 2.11] | 0.07 | 7 |
| $C_{5,13}$ | [7.20, 9.40] | [0.78, 0.96] | [0.29, 2.07] | 0.05 | 5 |
| $C_{5,14}$ | [6.80, 8.20] | [0.78, 0.92] | [0.54, 1.80] | 0.00 | 1 |
| $C_{5,15}$ | [8.40, 9.80] | [0.58, 0.84] | [1.34, 4.12] | 0.43 | 28 |
| $C_{5,16}$ | [6.40, 8.60] | [0.78, 0.96] | [0.26, 1.89] | 0.01 | 2 |
| $C_{5,17}$ | [7.80, 9.60] | [0.78, 0.92] | [0.62, 2.11] | 0.07 | 7 |
| $C_{5,18}$ | [5.80, 8.40] | [0.56, 0.78] | [1.28, 3.70] | 0.38 | 25 |
| $C_{5,19}$ | [6.60, 9.20] | [0.60, 0.90] | [0.66, 2.48] | 0.15 | 11 |
| $C_{61}$ | [5.80, 8.40] | [0.72, 0.94] | [0.35, 2.35] | 0.11 | 9 |
| $C_{62}$ | [7.20, 9.40] | [0.78, 0.96] | [0.29, 2.07] | 0.05 | 5 |
| $C_{63}$ | [5.60, 7.80] | [0.78, 0.92] | [0.45, 1.72] | 0.00 | 1 |
| $C_{64}$ | [7.20, 9.40] | [0.58, 0.84] | [1.15, 3.95] | 0.40 | 26 |
| $C_{71}$ | [5.80, 8.40] | [0.78, 0.96] | [0.23, 1.85] | 0.00 | 1 |
| $C_{72}$ | [7.20, 9.40] | [0.72, 0.94] | [0.43, 2.63] | 0.17 | 12 |
| $C_{73}$ | [7.20, 9.40] | [0.58, 0.84] | [1.15, 3.95] | 0.40 | 26 |
| $C_{74}$ | [5.60, 7.80] | [0.60, 0.90] | [0.56, 3.12] | 0.25 | 16 |
| $C_{75}$ | [4.60, 6.00] | [0.72, 0.94] | [0.28, 1.68] | 0.00 | 1 |
| $C_{76}$ | [7.80, 9.60] | [0.78, 0.96] | [0.31, 2.11] | 0.06 | 6 |
| $C_{77}$ | [5.60, 7.80] | [0.78, 0.92] | [0.45, 1.72] | 0.00 | 1 |
| $C_{78}$ | [7.20, 9.40] | [0.58, 0.84] | [1.15, 3.95] | 0.40 | 26 |

| | | | | | |
|---|---|---|---|---|---|
| $C_{79}$ | [5.60, 7.80] | [0.78, 0.96] | [0.22, 1.72] | 0.00 | 1 |
| $C_{7,10}$ | [7.20, 9.40] | [0.72, 0.94] | [0.43, 2.63] | 0.17 | 12 |
| $C_{7,11}$ | [7.20, 9.40] | [0.56, 0.78] | [1.58, 4.14] | 0.46 | 29 |
| $C_{7,12}$ | [5.60, 7.80] | [0.60, 0.90] | [0.56, 3.12] | 0.25 | 16 |
| $C_{81}$ | [4.60, 6.00] | [0.72, 0.94] | [0.28, 1.68] | 0.00 | 1 |
| $C_{82}$ | [6.00, 9.00] | [0.78, 0.96] | [0.24, 1.98] | 0.03 | 3 |
| $C_{83}$ | [5.60, 7.80] | [0.78, 0.92] | [0.45, 1.72] | 0.00 | 1 |
| $C_{84}$ | [5.80, 8.40] | [0.58, 0.84] | [0.93, 3.53] | 0.33 | 21 |
| $C_{85}$ | [7.80, 9.60] | [0.78, 0.96] | [0.31, 2.11] | 0.06 | 6 |
| $C_{86}$ | [6.60, 6.20] | [0.72, 0.94] | [0.40, 1.74] | 0.00 | 1 |
| $C_{87}$ | [6.20, 8.00] | [0.58, 0.84] | [0.99, 3.36] | 0.31 | 19 |
| $C_{88}$ | [7.80, 9.60] | [0.60, 0.90] | [0.78, 3.84] | 0.36 | 23 |
| $C_{89}$ | [6.40, 8.60] | [0.78, 0.92] | [0.51, 1.89] | 0.01 | 2 |
| $C_{8,10}$ | [7.20, 9.40] | [0.78, 0.96] | [0.29, 2.07] | 0.05 | 5 |
| $C_{8,11}$ | [8.40, 9.80] | [0.78, 0.92] | [0.67, 2.16] | 0.08 | 8 |
| $C_{8,12}$ | [6.60, 6.20] | [0.60, 0.90] | [0.66, 2.48] | 0.15 | 11 |
| $C_{8,13}$ | [7.80, 9.60] | [0.72, 0.94] | [0.47, 2.69] | 0.18 | 13 |
| $C_{8,14}$ | [5.60, 7.80] | [0.72, 0.94] | [0.34, 2.18] | 0.08 | 8 |
| $C_{8,15}$ | [7.20, 9.40] | [0.56, 0.78] | [1.58, 4.14] | 0.46 | 29 |
| $C_{8,16}$ | [7.20, 9.40] | [0.60, 0.90] | [0.72, 3.76] | 0.35 | 22 |
| $C_{8,17}$ | [6.40, 8.60] | [0.72, 0.94] | [0.38, 2.41] | 0.13 | 10 |
| $C_{8,18}$ | [4.80, 6.60] | [0.72, 0.94] | [0.29, 1.85] | 0.00 | 1 |
| $C_{8,19}$ | [6.00, 9.00] | [0.60, 0.90] | [0.60, 3.60] | 0.32 | 20 |
| $C_{8,20}$ | [5.80, 8.40] | [0.58, 0.84] | [0.93, 3.53] | 0.33 | 21 |
| $C_{8,21}$ | [6.00, 9.00] | [0.78, 0.96] | [0.24, 1.98] | 0.03 | 3 |
| $C_{8,22}$ | [8.40, 9.80] | [0.72, 0.94] | [0.50, 2.74] | 0.19 | 14 |
| $C_{8,23}$ | [8.40, 9.80] | [0.56, 0.78] | [1.85, 4.31] | 0.50 | 30 |
| $C_{8,24}$ | [5.40, 7.20] | [0.60, 0.90] | [0.54, 2.88] | 0.22 | 15 |

Table 6.19: Overall grey performance rating of alternators

| Alternator (C) | Rating (U) | Overall grey performance rating(U) | Ideal values of Overall grey performance rating $\max(\overline{G}_{ideal}\text{-}\underline{G}_{ideal})$ | Grey possibility degree between (GPII) of two attributes under same capacity, $\max[(0, L^* - \max(0, \overline{G}_{ideal} - \underline{G}_i)]$ | Rating |
|---|---|---|---|---|---|
| C(A1) | U(A1) | [2.88, 12.75] | [3.81,15.94] | 0.406 | 2 |
| C(A2) | U(A2) | [3.81, 15.94] | | 0.500 | 4 |
| C(A3) | U(A3) | [1.58, 7.25] | | 0.193 | 1 |
| C(A4) | U(A4) | [3.73, 15.11] | | 0.481 | 3 |

Table 6.20: Initial decision-making matrix with values expressed using intervals grey numbers

| | $C_1$ | | $C_2$ | | $C_3$ | | $C_4$ | | $C_5$ | | $C_6$ | | $C_7$ | | $C_8$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Significance | 0.125 | | 0.125 | | 0.125 | | 0.125 | | 0.125 | | 0.125 | | 0.125 | | 0.125 | |
| Optimization | max | | max | | max | | max | | max | | max | | max | | max | |
| Alternatives | $\underline{x}_{1j}$ | $\overline{x}_{1j}$ | $\underline{x}_{2j}$ | $\overline{x}_{2j}$ | $\underline{x}_{3j}$ | $\overline{x}_{3j}$ | $\underline{x}_{4j}$ | $\overline{x}_{4j}$ | $\underline{x}_{5j}$ | $\overline{x}_{5j}$ | $\underline{x}_{6j}$ | $\overline{x}_{6j}$ | $\underline{x}_{7j}$ | $\overline{x}_{7j}$ | $\underline{x}_{8j}$ | $\overline{x}_{8j}$ |
| A1 | 3.67 | 8.99 | 4.17 | 11.12 | 3.77 | 9.77 | 3.55 | 8.55 | 4.09 | 9.79 | 2.78 | 6.77 | 3.97 | 10.18 | 3.80 | 9.61 |
| A2 | 5.07 | 11.96 | 5.05 | 13.13 | 4.71 | 11.60 | 4.85 | 11.20 | 5.12 | 11.68 | 4.84 | 11.06 | 5.30 | 12.16 | 5.11 | 12.27 |
| A3 | 1.93 | 5.23 | 1.93 | 5.59 | 2.19 | 5.65 | 1.76 | 4.79 | 2.35 | 5.67 | 1.73 | 4.68 | 2.32 | 5.67 | 2.03 | 5.45 |
| A4 | 5.12 | 11.73 | 4.84 | 12.26 | 4.58 | 11.14 | 5.39 | 11.58 | 5.03 | 11.05 | 5.01 | 11.19 | 4.79 | 11.27 | 4.95 | 11.25 |

Table 6.21: Normalized decision-making matrix

| | $C_1$ | | $C_2$ | | $C_3$ | | $C_4$ | | $C_5$ | | $C_6$ | | $C_7$ | | $C_8$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Significance | 0.125 | | 0.125 | | 0.125 | | 0.125 | | 0.125 | | 0.125 | | 0.125 | | 0.125 | |
| Optimization | max | | max | | max | | max | | max | | max | | max | | max | |
| Alternatives | $\underline{x}^*_{1j}$ | $\overline{x}^*_{1j}$ | $\underline{x}^*_{2j}$ | $\overline{x}^*_{2j}$ | $\underline{x}^*_{3j}$ | $\overline{x}^*_{3j}$ | $\underline{x}^*_{4j}$ | $\overline{x}^*_{4j}$ | $\underline{x}^*_{5j}$ | $\overline{x}^*_{5j}$ | $\underline{x}^*_{6j}$ | $\overline{x}^*_{6j}$ | $\underline{x}^*_{7j}$ | $\overline{x}^*_{7j}$ | $\underline{x}^*_{8j}$ | $\overline{x}^*_{8j}$ |
| A1 | 0.243 | 0.594 | 0.252 | 0.672 | 0.252 | 0.653 | 0.187 | 0.449 | 0.270 | 0.645 | 0.203 | 0.495 | 0.256 | 0.655 | 0.248 | 0.628 |
| A2 | 0.335 | 0.790 | 0.305 | 0.793 | 0.315 | 0.775 | 0.255 | 0.589 | 0.338 | 0.770 | 0.354 | 0.808 | 0.341 | 0.783 | 0.334 | 0.802 |
| A3 | 0.128 | 0.346 | 0.117 | 0.338 | 0.146 | 0.377 | 0.093 | 0.252 | 0.155 | 0.374 | 0.126 | 0.342 | 0.149 | 0.365 | 0.133 | 0.356 |
| A4 | 0.338 | 0.775 | 0.292 | 0.741 | 0.306 | 0.744 | 0.283 | 0.609 | 0.332 | 0.728 | 0.366 | 0.818 | 0.308 | 0.725 | 0.323 | 0.735 |

Table 6.22: The ranking results obtained using extended Ratio system part of the MOORA method, ($\lambda$=0.5)

| Alternatives | $\sum s_{ij}\underline{x}^*_{1j}$ | $\sum s_{ij}\overline{x}^*_{1j}$ | $y^* = (1-\lambda)\sum \underline{x}^*_{1j} + (\lambda)\sum \overline{x}^*_{1j}$ | Ranking |
|---|---|---|---|---|
| A1 | 0.239 | 0.599 | 0.419 | 2 |
| A2 | 0.322 | 0.764 | 0.543 | 4 |
| A3 | 0.131 | 0.344 | 0.237 | 1 |
| A4 | 0.319 | 0.734 | 0.527 | 3 |

Table 6.23: Ranking results obtained using GREY method and MOORA method

| | GREY | | MOORA | |
|---|---|---|---|---|
| Alternatives | GPII | Ranking | $y^*(\lambda = 0.5)$ | Ranking |
| A1 | 0.406 | 2 | 0.419 | 2 |
| A2 | 0.500 | 4 | 0.543 | 4 |
| A3 | 0.193 | 1 | 0.237 | 1 |
| A4 | 0.481 | 3 | 0.527 | 3 |

Table 6.24: Ranking results obtained using extended ratio system part of the MOORA method and different values of $\lambda$.

| Alternatives | Y*(λ=0) | Ranking | Y*(λ =0.5) | Ranking | Y*(λ=1) | Ranking |
|---|---|---|---|---|---|---|
| A1 | 0.239 | 2 | 0.419 | 2 | 0.599 | 2 |
| A2 | 0.322 | 4 | 0.543 | 4 | 0.764 | 4 |
| A3 | 0.131 | 1 | 0.237 | 1 | 0.344 | 1 |
| A4 | 0.319 | 3 | 0.527 | 3 | 0.734 | 3 |

Table 6.25: Reference grey point and distances to reference grey point

| | C1 | | C2 | | C3 | | C4 | | C5 | | C6 | | C7 | | C8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Significance | 0.125 | | 0.125 | | 0.125 | | 0.125 | | 0.125 | | 0.125 | | 0.125 | | 0.125 | |
| Optimization | max | | max | | max | | max | | max | | max | | max | | max | |
| $\otimes r$ | $\underline{r}_1$ | $\overline{r}_1$ | $\underline{r}_2$ | $\overline{r}_2$ | $\underline{r}_3$ | $\overline{r}_3$ | $\underline{r}_4$ | $\overline{r}_4$ | $\underline{r}_5$ | $\overline{r}_5$ | $\underline{r}_6$ | $\overline{r}_6$ | $\underline{r}_7$ | $\overline{r}_7$ | $\underline{r}_8$ | $\overline{r}_8$ |
| Reference point | 0.128 | 0.79 | 0.117 | 0.793 | 0.146 | 0.775 | 0.093 | 0.609 | 0.155 | 0.77 | 0.126 | 0.818 | 0.149 | 0.783 | 0.133 | 0.802 |
| Alternatives | $\underline{d}_{1j}$ | $\overline{d}_{1j}$ | $\underline{d}_{2j}$ | $\overline{d}_{2j}$ | $\underline{d}_{3j}$ | $\overline{d}_{3j}$ | $\underline{d}_{4j}$ | $\overline{d}_{4j}$ | $\underline{d}_{5j}$ | $\overline{d}_{5j}$ | $\underline{d}_{6j}$ | $\overline{d}_{6j}$ | $\underline{d}_{7j}$ | $\overline{d}_{7j}$ | $\underline{d}_{8j}$ | $\overline{d}_{8j}$ |
| A1 | 0.115 | 0.196 | 0.135 | 0.121 | 0.106 | 0.122 | 0.094 | 0.160 | 0.115 | 0.125 | 0.077 | 0.323 | 0.107 | 0.128 | 0.115 | 0.174 |
| A2 | 0.207 | 0.000 | 0.188 | 0.000 | 0.169 | 0.000 | 0.162 | 0.020 | 0.183 | 0.000 | 0.228 | 0.010 | 0.192 | 0.000 | 0.201 | 0.000 |
| A3 | 0.000 | 0.444 | 0.000 | 0.455 | 0.000 | 0.398 | 0.000 | 0.357 | 0.000 | 0.396 | 0.000 | 0.476 | 0.000 | 0.418 | 0.000 | 0.446 |
| A4 | 0.210 | 0.015 | 0.175 | 0.052 | 0.160 | 0.031 | 0.190 | 0.000 | 0.177 | 0.042 | 0.240 | 0.000 | 0.159 | 0.058 | 0.190 | 0.067 |

Table 6.26: Distances of any alternative to reference point, for ($\lambda$ =0)

| | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Significance | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 | | |
| Optimization | max | max | max | max | max | max | max | max | | |
| Alternatives | $d_{1j}$ | $d_{2j}$ | $d_{3j}$ | $d_{4j}$ | $d_{5j}$ | $d_{6j}$ | $d_{7j}$ | $d_{8j}$ | $\max_i d_{ij}$ | Ranking |
| A1 | 0.0147 | 0.0169 | 0.0132 | 0.0117 | 0.0143 | 0.0096 | 0.0133 | 0.0144 | 0.0169 | 2 |
| A2 | 0.0265 | 0.0235 | 0.0211 | 0.0202 | 0.0228 | 0.0285 | 0.0240 | 0.0251 | 0.0285 | 3 |
| A3 | 0.0001 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 1 |
| A4 | 0.0269 | 0.0219 | 0.0200 | 0.0238 | 0.0221 | 0.0300 | 0.0199 | 0.0238 | 0.0300 | 4 |

Table 6.27: Distances of any alternative to reference point, for ($\lambda$ =1)

| | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Significance | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 | | |
| Optimization | max | max | max | max | max | max | max | max | | |
| Alternatives | $d_{1j}$ | $d_{2j}$ | $d_{3j}$ | $d_{4j}$ | $d_{5j}$ | $d_{6j}$ | $d_{7j}$ | $d_{8j}$ | $\max_i d_{ij}$ | Ranking |
| A1 | 0.0245 | 0.0151 | 0.0153 | 0.0199 | 0.0156 | 0.0404 | 0.0160 | 0.0218 | 0.0404 | 3 |
| A2 | 0.0000 | 0.0000 | 0.0000 | 0.0025 | 0.0000 | 0.0012 | 0.0000 | 0.0000 | 0.0025 | 1 |
| A3 | 0.0555 | 0.0569 | 0.0497 | 0.0447 | 0.0495 | 0.0595 | 0.0523 | 0.0557 | 0.0595 | 4 |
| A4 | 0.0018 | 0.0065 | 0.0039 | 0.0000 | 0.0052 | 0.0000 | 0.0072 | 0.0084 | 0.0084 | 2 |

Table 6.28: Distances of any alternative to reference point, for ($\lambda$=0.5)

| | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Significance | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 | | |
| Optimization | max | max | max | max | max | max | max | max | | |
| Alternatives | $d_{1j}$ | $d_{2j}$ | $d_{3j}$ | $d_{4j}$ | $d_{5j}$ | $d_{6j}$ | $d_{7j}$ | $d_{8j}$ | $\max_{i} d_{ij}$ | Ranking |
| A1 | 0.019 | 0.016 | 0.014 | 0.016 | 0.015 | 0.025 | 0.134 | 0.018 | 0.134 | 2 |
| A2 | 0.013 | 0.012 | 0.011 | 0.011 | 0.011 | 0.015 | 0.228 | 0.013 | 0.228 | 4 |
| A3 | 0.028 | 0.028 | 0.025 | 0.022 | 0.025 | 0.030 | 0.026 | 0.028 | 0.030 | 1 |
| A4 | 0.014 | 0.014 | 0.012 | 0.012 | 0.014 | 0.015 | 0.193 | 0.016 | 0.193 | 3 |

Table 6.29: Ranking results obtained using extended Ratio system approach of the MOORA method and different values of $\lambda$

| $\lambda$ | ($\lambda$=0) | | ($\lambda$=0.5) | | ($\lambda$=1) | |
|---|---|---|---|---|---|---|
| Alternatives | $\max_{i} d_{ij}$ | Ranking | $\max_{i} d_{ij}$ | Ranking | $\max_{i} d_{ij}$ | Ranking |
| A1 | 0.0169 | 2 | 0.134 | 2 | 0.0245 | 3 |
| A2 | 0.0285 | 3 | 0.228 | 4 | 0.0025 | 1 |
| A3 | 0.0001 | 1 | 0.030 | 1 | 0.0595 | 4 |
| A4 | 0.0300 | 4 | 0.193 | 3 | 0.0084 | 2 |

Table 6.30: Final ranking order by dominance theory exploring different parts of grey-MOORA

| Alternatives | Grey approach | | Grey -MOORA | | | | | | | | | | | | Final Ranking order (Dominance Theory) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ratio system approach Y* | | | | | | Reference point approach $\max_{i} d_{ij}$ | | | | | | |
| | GPII | Rank | ($\lambda$=0) | Rank | ($\lambda$=0.5) | Rank | ($\lambda$=1) | Rank | ($\lambda$=0) | Rank | ($\lambda$=0.5) | Rank | ($\lambda$=1) | Rank | |
| SC1 | 0.406 | **2** | 0.239 | **2** | 0.419 | **2** | 0.599 | **2** | 0.017 | **2** | 0.134 | **2** | 0.024 | **3** | **2** |
| SC2 | 0.500 | **4** | 0.322 | **4** | 0.543 | **4** | 0.764 | **4** | 0.028 | **3** | 0.228 | **4** | 0.003 | **1** | **4** |
| SC3 | 0.193 | **1** | 0.131 | **1** | 0.237 | **1** | 0.344 | **1** | 0.000 | **1** | 0.03 | **1** | 0.059 | **4** | **1** |
| SC4 | 0.481 | **3** | 0.319 | **3** | 0.527 | **3** | 0.734 | **3** | 0.030 | **4** | 0.193 | **3** | 0.008 | **2** | **3** |

# CHAPTER 7

## Contributions of the Present Dissertation: Scope for Future Research

Contributions of the present dissertation have been summarized below.
In the present dissertation, focus has been made to develop a variety of decision support systems (evaluation index systems or frameworks) towards assessment of SC performance extent based on some integrated criteria hierarchies (consisting of main performance indices as well as sub-indices).

Subjectivity associated in expressing priority weight as well as appropriateness rating of individual performance indicators (SC performance measures and metrics) invites extent of uncertainty, imprecision as well as vagueness during decision making; this has been overcome through systematic and logical exploration of fuzzy logic and grey theory as well.

Subjective evaluation inform thus collected from the assumed expert group has been analyzed to determine an overall performance metric (performance index) of the organizational supply chain. The following decision support tools have been attempted in this research.

1. Fuzzy embedded performance appraisement module in combination with modified version of Deng's similarity based method.
2. SC performance appraisement platform using Generalized Fuzzy Numbers Set (GFNS) theory.
3. Evaluation of SC performance index based on Generalized Interval-Valued Fuzzy Numbers Set (GIVFNs) theory.
4. SC performance assessment: Exploration of grey numbers set theory.

Supply chain performance benchmarking has also been attempted using (i) Fuzzy-MULTIMOORA and (ii) Fuzzy-Grey relation method and (iii) Grey-MULTIMOORA. Assuming a set of candidate industries/enterprises (operating under similar SC architecture); industries have been ranked in accordance to the ongoing SC performance extent.

Apart from assessing SC's overall performance extent; attempts have also been made to identify ill (week) performing areas of the supply chain network. For the decision support systems those have been developed to operate in fuzzy environment; the concept of 'degree of similarity' (DOS) (between two fuzzy numbers) has been demonstrated as an 'effective mean' towards deriving performance ranking order of various SC performance indices. For the decision support system which utilizes GFNS theory, it has been observed that the concept of

DOS may effectively be explored instead of using the concept of fuzzy numbers ranking by 'maximizing set and minimizing set' in course of deriving performance ranking order of SC evaluation indices and thus identifying ill-performing SC entities.

The research fruitfully explored the concept of 'grey possibility degree' (in identifying ill-performing SC entities) for the decision support system which has been presented to operate under grey environment.

The application potential of Fuzzy-MULTIMOORA, fuzzy-grey relation method as well as grey-MULTIMOORA have been tested in this research in course of SC performance benchmarking: selection of the best industry/enterprise (it's SC) amongst the set of possible alternatives (industries) operating on similar SC model. However, the main disadvantage of these models is that these approaches cannot provide a unique performance index highlighting SC's overall performance extent. These are approaches are helpful in pursuit of performance benchmarking.

Procedural steps of the proposed decision support systems followed by empirical data analysis in detail, have been provided in this dissertation for better understanding on the issues discussed so far from managerial viewpoint.

The objectives of the empirical data analysis and the outcomes/ means of accomplishing them have been summarized below in a tabular form.

| **Objectives** | **Means of accomplishing them** |
|---|---|
| To develop efficient as well as flexible decision support tools for systematic and logical appraisement of SC performance | Exploration of multi-layered criteria hierarchy towards SC's performance evaluation<br>Application of decision-making module based on fuzzy/grey numbers set theory |
| Identification of ill (poor)-performing areas of SC | Exploration of the theories of fuzzy numbers ranking by 'Maximizing Set and Minimizing Set' and fuzzy degree of similarity towards evaluating performance ranking order of various sub-criterions based on their FPII |
| Ranking (and selection of the best) of alternative enterprises (running under similar SC architecture) in view of ongoing SC overall performance | Exploration of Fuzzy MOORA, Grey MOORA and fuzzy grey relation method |

Within current scope and limitations, aforesaid research can be extended in the following directions.

The work proposes different appraisement modules in quantifying supply chain performance in fuzzy (as well as grey) context. Computational part of the work is based on empirical data. The appraisement models as well as procedural framework thus proposed need to be applied in real organizational supply chains in order to analyze existing performance scenarios across different industries, to seek for identifying ill-performing areas and also to compare SC performance extent of different industries (that follow supply chain of similar type) for obtaining the ranking order (benchmarking). This may help industries in facilitating various decisions making.

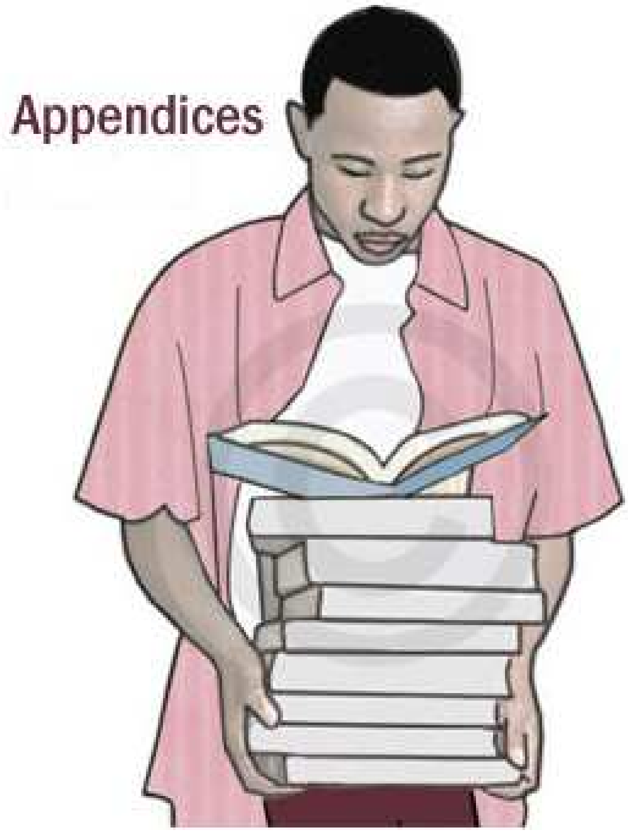
One part of this work proposes exploration of generalized fuzzy numbers as well as generalized interval-valued fuzzy numbers set theories to aid the said decision making. The linguistic as well as fuzzy scale chosen for gathering decision making information are based on previous literature. However, the appropriateness and validity of the scales chosen has not been justified. Moreover, the relative advantage and disadvantage of using GTFNs and INFNs theories have not been tested. Apart from trapezoidal fuzzy numbers, there exists triangular, Gaussian, bell-shaped fuzzy numbers (corresponding Membership Functions) in fuzzy set theory. The research assumes that selection of the particular fuzzy number and corresponding membership function are completely predefined at the top managerial level. Though, it is clearly unknown which fuzzy membership function would provide highest accuracy and prediction results.

The proposed fuzzy/grey based appraisement modules end at identifying ill-performing areas of the supply chain. However, possible means to improve performance level of those areas have not been discussed. Research can be extended to find out effective action plans to boost up performance degree of different ill-performing SC areas and to implement it in practice. Once it is implemented, again overall supply chain performance has to be reevaluated to check mathematically whether overall performance level is actually incremented or not.

The work utilizes empirical data assuming provided by a group of decision makers (experts). However, the optimal data set (number of decision makers) required towards achieving a fruitful and realistic result, has not been investigated yet. It is believed that there must be a definite relation between evaluation criteria hierarchy (number of criteria as well as sub-criteria) and the required sample size (total number of decision makers). From the knowledge of statistics, it is assumed that more the data, more accurate would be the prediction result. In real world, data collection from a large group of decision makers is really a tedious task. It requires active as well as prompt participation of the experts without any biasness at the personal level. A lengthy questionnaire consumes considerable time; and hence participants may neither keep patience nor may be interested at all to provide sufficient as well as realistic evaluation information. Moreover, this linguistic decision making information may not be always complete and consistent. Therefore, a compromise must be made in finalizing the optimal data set for the analysis purpose. A lesser data set may provide erroneous result.

The decision support systems thus provided have neither been validated (by practical case example) nor tested for reliability checking.

Different appraisement platforms have been explored from various literature resources. It must be investigated whether these criteria-hierarchies are industry specific or may vary differently for different industry/sectors. Therefore, the criteria-hierarchy may require to be standardized.
Aforementioned aspects may be investigated in future work.




# Appendices

## APPENDIX-A

| Definition/explanation of SC performance indicators (Refer to Table 2.1) | |
|---|---|
| **Performance indicator(s)** | **Definition/Explanation** |
| Strategic (management) performance | Strategic management is a systematic approach of analyzing, planning and implementing the strategy in an organization to ensure a continued success. Strategic management is a long term procedure which helps the organization in achieving a long term goal; its overall responsibility lies with the general management team. It focuses on building a solid foundation that will be subsequently achieved by the combined efforts of each and every employee of the organization. [Source: www.smusolutions.com] |
| Total cash flow time | A company's cash inflows and cash outflows and the business activities that caused them over a given period of time. [Source: www.financial-dictionary.thefreedictionary.com] |
| Rate of return on investment | A measure of the net income a firm's management is able to earn with the total assets. Return on investment is calculated by dividing net profits after taxes by total assets. This is also called rate of return, return on assets. [Source: www.financial-dictionary.thefreedictionary.com] |
| Flexibility to meet particular customer needs | Problems that customers intend to solve with the purchase of a good or service. Care must be taken to fulfill customer expectations and customer requirements. [Source: www.toolingu.com] |
| Delivery lead time | From the time a confirmed sales order is punched till the product is delivered. |
| Total cycle time | The period required to complete one cycle of an operation; or to complete a function, job, or task from start to finish. Cycle time is used in differentiating total duration of a process from its run time. [Source: www.businessdictionary.com] |
| Buyer-supplier partnership level | Extended relationship between buyer-supplier must be maintained based on confidence, credibility, and mutual benefit. The buyer, on its part, provides long-term contracts and assurance of only a small number of competing suppliers. In reciprocation, the seller implements customer's suggestions and commits to continuous improvement in quality of product and delivery. [Source: www.businessdictionary.com] |
| Customer query time | Time taken to respond against request for a specific product of information from customers. |
| Tactical performance | Involving or pertaining to actions, ends, or means that are immediate or short-term in duration, and/or lesser in importance or magnitude, than those of a strategy or a larger purpose. [Source: www.businessdictionary.com] |
| Extent of cooperation to improve quality | Confidence in a supplier's ability to deliver a good or service that will satisfy the customer's needs. It is achievable through interactive relationship between the customer and the supplier; it aims at ensuring the product's 'fit' to the customer's requirements with little or no adjustment or inspection. So quality must be improved according to customer demand. [Source: www.businessdictionary.com] |
| Total transportation cost | The total transportation cost of a company incurs when it transfers its inventory or other assets to another location. |
| Truthfulness of demand | Truthfulness of demand evidenced by customers' orders and allocation of inventory. |
| Predictability/forecasting | The need for forecasting stems from the time lag between awareness of an impending event or need and the occurrence of that |

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|---|---|
| methods | event. Forecasting method helps towards prediction of future events and conditions and is a key element in service organizations, especially for management decision-making. [Source: www.isixsigma.com] |
| Product development cycle time | System of defined steps and tasks such as strategy, organization, concept generation, marketing plan creation, evaluation, and commercialization of a new product. It is a cycle time by means of which an innovative firm routinely converts ideas into commercially viable goods or services. [Source: www.businessdictionary.com] |
| Operational performance | Jobs or tasks consisting of one or more elements or subtasks, performed typically in one location. Operations transform resource or data inputs into desired goods, services, or results, and create and deliver value to the customers. [Source: www.businessdictionary.com] |
| Manufacturing cost | The total cost of manufacturing a product, including the direct labor costs, direct material costs, overhead costs, and any other expenses associated with production. Manufacturing costs are generally separated from other expenses in order to gauge the efficiency and productivity of the company. [Source: www.investorwords.com] |
| Capacity utilization | A firm's productive capacity is the total level of output or production that it could produce in a given time period. Capacity utilization is the percentage of the firm's total possible production capacity that is actually being used. [ Source: www.tutor2u.net] |
| Information carrying/sharing cost | Information is said to be the glue that holds supply chains together. As a key infrastructure, Web-based technologies continue to have significant impact on supply chain strategies. On the coordination side, the Web provides a virtually free platform for enhancing transparency, eliminating information delays and distortions, and significantly reducing transaction costs. One should note, however, that, although information flow has accelerated considerably, material flow has not gained much speed. This phenomenon makes the coordination of material, information, and cash flows even more crucial for effective supply chain coordination. On the design side, current technology does not yet permit dynamic supply chain design in response to changing business environment. The adoption of Web Services represents a significant step in that direction. [Source: Yücesan E (2007) Impact of Information Technology on Supply Chain Management, Trends in Supply Chain Design and Management , Springer Series in Advanced Manufacturing, pp. 127-148] |
| Inventory carrying cost | The cost of holding goods in stock. Expressed usually as a percentage of the inventory value and includes cost of capital, warehousing, depreciation, insurance, taxation, obsolescence, and shrinkage. [Source: www.businessdictionary.com] |

## APPENDIX-B

| Definition/explanation of SC performance indicators (Refer to Table 3.1) | |
|---|---|
| **Performance indicator(s)** | **Definition/Explanation** |
| Customer Satisfaction Degree | Customer satisfaction is consumer's judgment that a product provided a pleasurable level of consumption-related fulfillment. |
| Order Fulfillment Rate | Order Fulfillment Rate, also known as demand satisfaction rate is a Percentage of consumption orders satisfied from stock available at a moment.<br>[Source: www.mbaskool.com] |
| Rate of Maintaining Customers | A supplier maintain better communicate with customers, effectively respond to their demands and act on customer's feedback periodically. |
| On-Time Delivery | The ability of an organization to fulfill shipping orders or other transactions within the period of time promised to a client or customer.<br>[Source: www.businessdictionary.com] |
| Product Quality | The central aspect of a product that is determined by the consumer and includes attributes such as safety, reliability, serviceability, and at tractability. Product quality is constantly changing to meet changing consumer demands.<br>[Source: www.toolingu.com] |
| Information Sharing Degree | Information sharing describes the exchange of data between various organizations, people and technologies.<br>[Source: www.techopedia.com] |
| Unit Information Cost | In cost accounting, unit of product or service for which cost is computed. Cost units are selected to allow for comparison between actual cost and standard cost, or between different actual costs.<br>[Source: www.businessdictionary.com] |
| Timeliness of Information Transmission | Timeliness of Information Transmission refers to whether information is up-to-date and available to the user in an acceptable timeframe. Timeliness of Information Transmission is mentioned in most frameworks on information quality. |
| Accuracy of Information Transmission | Accuracy of Information Transmission is helpful to the managers to take the correct decision for an organization. |
| Utilization Rate of Information | The proportion of the available time (expressed usually as a percentage) that the information or a system is operating, i.e. (Utilizing information x 100 ÷ available Information). |
| Logistics Performance | Logistics performance may be defined as the systematic and objective search for, and analysis of, information relevant to the identification and solution of any problem in the field of logistics.<br>[Source: Chow G, Henriksson LE (1993) A Critique of Survey Research in Logistics, Working Paper 93-TRA-009, University of British Columbia, Faculty of Commerce and Business Administration] |
| Transport Loss Rate | The losses during transport in specific time bound. |
| Utilization Rate of Warehouse | Warehouse utilization is an enterprise software application that automates and manages the processes of an organization's warehouse. Warehouse utilization provides a centralized software interface for processing, managing and monitoring a warehouse's operational processes. Warehouse management system may also be called an inventory management system and |

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| | store management system.<br>[Source: www.techopedia.com] |
| Stock Turnover Rate | Number of times a firm's investment in stock is recouped during an accounting period. Normally a high number indicates a greater sales efficiency and a lower risk of loss through un-saleable stock. However, a Stock turnover that is out of proportion to industry norms may suggest losses due to shortages, and poor customer-service.<br>[Source: www.businessdictionary.com] |
| Financial Performance | Measuring the results of a firm's policies and operations in monetary terms. These results are reflected in the firm's return on investment, return on assets, value added, etc.<br>[Source: www.businessdictionary.com] |
| Profit-to-Cost Ratio | Profit-to-Cost Ratio determines how well a business or corporation handles the management of profits and costs.<br>[Source: www.businessdictionary.com] |
| Profit Growth Rate | The amount of increase that a specific variable has gained within a specific period and context. For investors, this typically represents the compounded annualized rate of growth of a company's revenues, earnings, dividends and even macro concepts - such as the economy as a whole.<br>[Source: www.investopedia.com] |
| Return on Net Worth | Determination of the ratio of an individual or business taxpayer's income to their overall net worth.<br>[Source: www.businessdictionary.com] |
| Capital Maintenance and Increment Ratio | Accounting concept that a profit can be realized only after capital of the firm has either been restored to its original level (called 'capital recovery') or is maintained at a predetermined level. It is necessary, therefore, to determine the value of capital before the amount of profit can be computed.<br>[Source: www.businessdictionary.com] |

## APPENDIX-C

| Definition/explanation of SC performance indicators (Refer to Table 3.11) | |
|---|---|
| Performance indicator(s) | Definitions/ Explanations |
| Supplying | The total amount of a product (good or service) available for purchase at any specified price. [Source: www.businessdictionary.com] |
| P & C Design | Realization of a concept or idea into a configuration, drawing, model, mould, pattern, plan or specification (on which the actual or commercial production of an item is based) and which helps achieve the item's designated objective(s). [Source: www.businessdictionary.com] |
| P & C Fabrication | Manufacturing process in which an item is made (fabricated) from raw or semi-finished materials instead of being assembled from ready-made components or parts. [Source: www.businessdictionary.com] |
| Delivery | Delivery implies physically moving something to the customer. |
| Delivery Cost | The financial value of the conveyance of the underlying commodities when a futures or forward contract expires. The delivery price is the price at which one party agrees to deliver the underlying commodity and at which the counterparty agrees to accept delivery. [Source: www.investopedia.com] |
| Delivery Reliability | Ratio of the number of deliveries made without any error (regarding time, place, price, quantity, and/or quality) to the total number of deliveries in a period. [Source: www.businessdictionary.com] |
| Timeliness of Delivery | In general, timeliness of a contract is deemed a warranty an incidental point and not a central point like a condition. Therefore, a failure to adhere to a time schedule would amount to a breach of warranty (for which the injured party may sue for damages) and not a breach of condition (for which the injured party may terminate the contract). If adherence to a schedule is vital, it must be made a specific condition by using precise wording (such as the traditional phrase, 'Time is of the essence') [Source: www.businessdictionary.com] |
| Error-Free | The process of eliminating the causes of error in a business or supply. Error cause removal is a key goal of process improvement methodologies such as Six Sigma, which uses a variety of process analysis techniques to identify and remedy the causes of errors in a supplying process. [Source: www.businessdictionary.com] |
| Delivery Flexibility | Suppliers are seeking to provide products which are more alternative choice of the customer of what, how, when and where they purchase and at what price. |
| Frequency | Rate of repetition of a cyclical or regular delivery, measured by cycles per second. |
| Amount | The amount charged for freight fees. This involves freight received by the company and freight sent out by the company. [Source: www.businessdictionary.com] |
| Inbound Logistics | The activities of receiving, storing, and disseminating incoming goods or material for use. [Source: www.businessdictionary.com] |
| Supply Base Management | Supply Base Management (SBM) is a systematic dynamic approach for strategically managing the whole supply base which might |

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| | include current suppliers, minor suppliers and potential suppliers. [Source: www.kbmanage.com] |
| Transportation | The process of shipping or moving an item from outside (raw material) to inside industry (manufacturing unit). |
| Transport Cost | The expenses involved in moving products or assets to a different place, which is often passed into the industry. [Source: www.businessdictionary.com] |
| Transport Productivity | A measure of the efficiency of transport. Productivity is computed by dividing average output per period by the total costs incurred or resources consumed in that period. [Source: www.businessdictionary.com] |
| Transport Flexibility | The ability of a system, such as a transportation process, to cost effectively varies its output within a certain range and given timeframe. [Source: www.businessdictionary.com] |
| Facility Utilization | A formal financial assistance offered by a lending institution to help a company that requires operating capital. Facility utilization is essentially another name for a loan taken out by a company. [Source: www.businessdictionary.com] |
| Receiving and Inspection | An administrative function that involves checking of the quality, quantity, and condition of the incoming goods followed by their proper storage. Critical appraisal involving examination, measurement, testing, gauging, and comparison of materials or items. An inspection determines if the material or item is in proper quantity and condition, and if it conforms to the applicable or specified requirements. [Source: www.businessdictionary.com] |
| Handling and Storing | Coordination and integration of operations such as un-packing, re-packing, packaging, and movement of materials or goods over short distances. It is related to the management of storehouses or warehouses, handling operations, and safe custody and protection of inventory items. [Source: www.businessdictionary.com] |
| Core Manufacturing | Key activity or cluster of activities which must be performed in an exemplary manner to ensure a manufacturing's continued competitiveness. [Source: www.businessdictionary.com] |
| Internal Manufacture Operations | Series of functions and tasks of manufacturing units that are involved in a single process. |
| Product Quality | The group of features and characteristics of a saleable good which determines its desirability and which can be controlled by a manufacturer to meet certain basic requirements. [Source: www.businessdictionary.com] |
| Operation Costs | The day-to-day expenses incurred in running a business, such as sales and administration, as opposed to production. [Source: www.investorwords.com] |
| Efficiency | The comparison of what is actually produced or performed with what can be achieved with the same consumption of resources. [Source: www.businessdictionary.com] |
| Flexibility | The ability of a system, such as a manufacturing process, to cost effectively varies its output within a certain range and given timeframe. |

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| | [Source: www.businessdictionary.com] |
| Productivity | A measure of the efficiency of a person, machine, factory, system, etc., in converting inputs into useful outputs. Productivity is computed by dividing average output per period by the total costs incurred or resources (capital, energy, material, personnel) consumed in that period. Productivity is a critical determinant of cost efficiency.<br>[Source: www.businessdictionary.com] |
| Research and Development | Systematic activities combining both basic and applied research, and are aimed at discovering solutions to problems or creating new goods and knowledge. R&D may result in ownership of intellectual property such as patents.<br>[Source: www.businessdictionary.com] |
| Technology and Engineering | The purposeful application of information in the design, production, and utilization of goods and services, and in the organization of human activities. The process of utilizing knowledge and principles to design, build, and analyze objects.<br>[Source: www.businessdictionary.com] |
| Maintenance and Storing | Actions necessary for retaining or restoring a piece of equipment, machine, or system to the specified operable condition to achieve its maximum useful life. It includes corrective maintenance and preventive maintenance. Non-transitory, semi-permanent or long-term, containment, holding, leaving, or placement of goods or materials, usually with the intention of retrieving them at a later time.<br>[Source: www.businessdictionary.com] |
| Outbound Logistics | The movement of material associated with storing, transporting, and distributing goods to its customers.<br>[Source: www.businessdictionary.com] |
| Transportation | The process of shipping or moving an item from inside (manufacturing unit) to outside (customer hand). |
| Warehousing | Performance of administrative and physical functions associated with storage of goods and materials. These functions include receipt, identification, inspection, verification, putting away, retrieval for issue, etc.<br>[Source: www.businessdictionary.com] |
| Warehouse Costs | The costs associated for storing goods in the warehouse. |
| Inventory Flow Rate | The inventory flow units that are handled by a business process per unit time. |
| Inventory Accuracy | When the on-hand quantity is equivalent to the perpetual balance (plus or minus the designated count tolerances).<br>[Source: ww.bowmanlogistics.com] |
| Stock Capacity | The total volume of products that can be placed on a warehouse. |
| Packing and Shipping | Practice of combining several related goods or services into a single offer. The process of transporting an item. Shipping is a very basic, common way of getting an item from one place to another, or from one person to another.<br>[Source: www.businessdictionary.com] |
| Marketing and Sales | Marketing is a process where a person identifies the needs and wants of people, determines and creates products or services that meet their needs and wants, how and where to deliver them, how to price them and how to promote the products. Sales is a process whereby one prospects people's needs, finds a solution to them, recommends it to the people in need then advocates their product and sells it to them. In both, they then create a transaction for exchanging the product for a certain value to create satisfaction to the buyer.<br>[Source: www.ask.com] |

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| Customer Order Processing and Delivery | The work that dealing with customer order and delivery. |
| Response Time | The response time is the interval between a customer order placed and the receipt of an action, result, or feedback from the vender. |
| Order Fill Rate | Percentage of customer or consumption orders satisfied from stock at hand. It is a measure of an inventory's ability to meet demand. [Source: www.businessdictionary.com] |
| Order Flexibility | An order that adjust very quickly to a fast changing marketplace and business environment. [Source: www.businessdictionary.com] |
| Frequency | The Rate of repetition of an order, measured cycles per second. |
| Amount | An order amount acceptable to a vendor. |
| Delivery Reliability | Ratio of the number of deliveries made without any error (regarding marketing and sales) to the total number of deliveries in a period. [Source: www.businessdictionary.com] |
| Advertising and Customer Services | To call the public's attention to your business, usually for the purpose of selling products or services, through the use of various forms of media, such as print or broadcast notices. [Source: www.entrepreneur.com] |

## APPENDIX-D

| Definition/explanation of SC performance indicators (Refer to Table 4.1) | |
|---|---|
| **Performance indicator(s)** | **Definitions/Explanations** |
| Strategic Performance | Organizations need to implement its strategy and deliver better performance. |
| Total Supply Chain Cycle Time | Cycle time is the end-to-end delay in a business process. The business processes are the supply chain processes; the order-to-delivery. [Source: www.classof1.com] |
| Total Cash Flow Time | Incomings and outgoings of cash, representing the operating activities of an organization in a year. [Source: www.businessdictionary.com] |
| Customer Query Time | Request for a specific product of information from customers. Organizations must respond faster to customer service enquiries. |
| Level of Customer Perceived Value of Product | A customer's opinion of a product's value to him/ her. It may have little or nothing to do with the product's market price, and depends on the product's ability to satisfy his/ her needs or requirements. [Source: www.businessdictionary.com] |
| Net Profit vs. Productivity Ratio | The amount by which income from sales is larger than all expenditure. A measure of the efficiency of a person, machine, factory, system, etc., in converting inputs into useful outputs. Productivity is computed by dividing average output per period by the total costs incurred or resources (capital, energy, material, personnel) consumed in that period. Productivity is a critical determinant of cost efficiency. [Source: www.businessdictionary.com] |
| Rate on Return on Investment | The earning power of assets measured as the ratio of the net income (profit less depreciation) to the average capital employed (or equity capital) in a company or project. It is expressed usually as a percentage; return on investment is a measure of profitability that indicates whether or not a company is using its resources in an efficient manner. [Source: www.businessdictionary.com] |
| Range of Product and Services | A set of variations of the same product platform that appeal to different market segments. Services are intangible products such as accounting, banking, cleaning, consultancy, education, insurance, expertise, medical treatment, or transportation. [Source: www.businessdictionary.com] |
| Variations Against Budget | A periodic measure used by governments, corporations or individuals to quantify the difference between budgeted and actual figures for a particular accounting category. A favorable budget variance refers to positive variances or gains; an unfavorable budget variance describes negative variance, meaning losses and shortfalls. Budget variances occur because forecasters are unable to predict the future with complete accuracy. As a result, some variance should be expected when budgets are created. [Source: www.investopedia.com] |
| Order Lead Time | Period between placing an order and receiving the ordered item. [www.businessdictionary.com] |
| Flexibility of Service Systems to Meet Particular Customer Needs | The ability of a system, such as services, to cost effectively varies its output within a certain range and given timeframe. The real or perceived value that a customer experiences or believes he/she is receiving through interaction with a company. Benefits may include resolution of a problem, achievement of a desired outcome or fulfillment of a need through a purchase; a |

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| | feeling of confidence following purchase; or satisfaction with post-purchase service.<br>[Source: www.businessdictionary.com] |
| Buyer-Supplier Partnership Level | Extended relationship between buyers and supplier must be maintained based on confidence, credibility, and mutual benefit. The buyer, on its part, provides long-term contracts and assurance of only a small number of competing suppliers. In reciprocation, the seller implements customer's suggestions and commits to continuous improvement in quality of product and delivery.<br>[Source: www.businessdictionary.com] |
| Supplier Lead Time Against Industry Norm | The amount of time that elapses between when a process starts and when it is completed. Lead time is examined closely in manufacturing, supply chain management and project management, as companies want to reduce the amount of time it takes to deliver products to the market. In business, lead time minimization is normally preferred. Generally accepted requirements followed by the members of an industry.<br>[Source: www.investopedia.com] |
| Level of Suppliers' Defect Free Deliveries | The ability of suppliers to maintain delivers the product to customer with zero defects. |
| Delivery Lead Time | From the time a confirmed sales order is punched till the time the product is delivered.<br>[Source: scn.sap.com] |
| Delivery Performance | The conditions in a sales or transportation contract that specify such things as the carrier, routing, freight charges, place of delivery, and time of delivery.<br>[Source: www.businessdictionary.com] |
| Tactical Performance | Involving or pertaining to actions, ends, or means that are immediate or short-term in duration, and/or lesser in importance or magnitude, than those of a strategy or a larger purpose.<br>[Source: www.businessdictionary.com] |
| Accuracy of Forecasting Techniques | Accuracy of forecasting is measured by (Error = Actual demand – forecast). Forecasting techniques help the management to handle uncertainty of the future, relying mainly on data from the past and present and analysis of trends. |
| Product Development Cycle Time | The time span required, from concept to market, to develop and produce a new product.<br>[Source: www2.intota.com] |
| Order Entry Methods | A buyer-generated document that authorizes a purchase transaction. When accepted by the seller, it becomes a contract binding on both parties. An order entry sets forth the descriptions, quantities, prices, discounts, payment terms, date of performance or shipment, other associated terms and conditions, and identifies a specific seller.<br>[Source: www.businessdictionary.com] |
| Effectiveness of Delivery Invoice Methods | A nonnegotiable commercial instrument issued by a seller to a buyer. It identifies both the trading parties and lists, describes, and quantifies the items sold, shows the date of shipment and mode of transport, prices and discounts (if any), and delivery and payment terms.<br>[Source: www.businessdictionary.com] |
| Purchase Order Cycle Time | The time span from when a company buys the production inputs to when those items arrive at the manufacturing plant. Purchase order lead time can have a significant impact on a company's bottom line. It is a key component of delivery cycle |

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| | time, along with the time it takes to make the product and the time it takes to deliver the product. |
| Planned Process Cycle Time | The planned time that elapses from the beginning to the end of a process. |
| Effectiveness of Master Production Schedule | A Master Production Schedule or MPS is the plan that a company has developed for production, inventory, staffing, etc. It sets the quantity of each end item to be completed in each week of a short-range planning horizon. A MPS is the master of all schedules. It is a plan for future production of end items. [Source: www.inventorysolutions.org] |
| Supplier Assistance in Solving Technical Problems | The process of working through details of a problem to reach a solution. Problem solving may include mathematical or systematic operations and can be a gauge of an individual's critical thinking skills. Suppliers' involvement is necessary in solving technical problems. [Source: www.businessdictionary.com] |
| Supplier Ability to Respond to Quality Problems | Confidence in a supplier's ability to deliver a good or service that would satisfy the customer's needs. It is achievable through interactive relationship between the customer and the supplier; it aims at ensuring the product's 'fit' to the customer's requirements with little or no adjustment or inspection. [Source: www.businessdictionary.com] |
| Supplier Cost Saving Initiatives | Measures implemented by a company to reduce its expenses and improve profitability. Cost saving measures may include lying off employees, reducing employee pay, switching to a less expensive employee health insurance program, downsizing to a smaller office, lowering monthly bills, changing hours of service and restructuring debt. [Source: www.investopedia.com] |
| Supplier's Booking in Procedure | Customer's concluded arrangement with a goods or services in relation to the supplier representing a completed sale. It is also called booking or transaction. |
| Delivery Reliability | Indicator of the number of deliveries made without any error (regarding time, place, price, quantity, and/or quality) to the total number of deliveries in a period. [Source: www.businessdictionary.com] |
| Responsiveness to Urgent Deliveries | Customs procedure under which an importer can take delivery of a shipment almost as soon as it is offloaded and inspected. It is affected through posting of a surety bond by the importer, or the customs retain a sample for appraisal of duties which are paid later. [Source: www.businessdictionary.com] |
| Effectiveness of Distribution Planning Schedule | Systematic process for determining which goods, in what quantity, at which location, and when are required in meeting anticipated demand. This inventory related information is then entered into a manufacturing requirements planning system as gross requirements for estimating input flows and production schedules. [Source: www.businessdictionary.com] |
| Operational Performance | Firm's operational performance measured against standard or prescribed indicators of effectiveness, efficiency, and environmental responsibility such as, cycle time, productivity, waste reduction, and regulatory compliance. [Source: www.businessdictionary.com] |
| Cost Per Operation Hour | Cost per unit time of a product or service, or the annual cost incurred on a continuous process. Operating costs do not include capital outlays or the costs incurred in design and implementation phases of a new process. |

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| | [Source: www.businessdictionary.com] |
| Information Carrying Cost | Information is said to be the glue that holds supply chains together. As a key infrastructure, Web-based technologies continue to have significant impact on supply chain strategies. On the coordination side, the Web provides a virtually free platform for enhancing transparency, eliminating information delays and distortions, and significantly reducing transaction costs. One should note, however, that, although information flow has accelerated considerably, material flow has not gained much speed. This phenomenon makes the coordination of material, information, and cash flows even more crucial for effective supply chain coordination. On the design side, current technology does not yet permit dynamic supply chain design in response to changing business environment. The adoption of Web Services represents a significant step in that direction. [Source: Yücesan E (2007) Impact of Information Technology on Supply Chain Management, Trends in Supply Chain Design and Management , Springer Series in Advanced Manufacturing, pp. 127-148] |
| Capacity Utilization | Extent or level to which the productive capacity of a plant, firm, or country is being used in generation of goods and services. Expressed usually as a percentage, it is computed by dividing the total capacity with the portion being utilized. [Source: www.businessdictionary.com] |
| Incoming Stock Level | The quantity of goods kept in stock. |
| Work-in-Progress | Material that has entered the production process but is not yet a finished product. Work in progress (WIP) therefore, refers to all materials and partly finished products that are at various stages of the production process. WIP excludes inventory of raw materials at the start of the production cycle and finished products inventory at the end of the production cycle. [Source: www.investopedia.com] |
| Scrap Level | The worth of a physical asset's individual components when the asset itself is deemed no longer usable. The individual components, known as 'scrap', are worth something, if they can be put to other uses. Sometimes scrap materials can be used as it is; other times they must be processed before they can be reused. |
| Finished Goods in Transit | Finished goods that have departed from the dispatch, loading, or shipping point but have not yet arrived at the receipt, offloading, or delivery point. It is also called in transit inventory or stock in transit. [Source: www.businessdictionary.com] |
| Supplier Rejection Rate | Assessment of existing or new suppliers on the basis of their delivery, prices, production capacity, quality of management, technical capabilities, and service. Supplier Rejection is decided by the decision makers. [Source: www.businessdictionary.com] |
| Quality of Delivery Documentation | A document accompanying a shipment of goods that lists the description and quantity of the goods delivered. A copy of the delivery documents, signed by the buyer or consignee, is returned to the seller or consignor as a proof of delivery. [Source: www.businessdictionary.com] |
| Efficiency of Purchase Order Cycle Time | A buyer-generated document that authorizes a purchase transaction. The period required to complete one purchase order cycle of an operation; or to complete a function, job, or task from start to finish. Purchase Order Cycle Time is used in differentiating total duration of a process from its run time. [Source: www.businessdictionary.com] |
| Frequency of Delivery | It is the Rate of repetition of delivery, measured cycles per day. |
| Quality of Delivered Goods | Maintaining the goods transported to the customer's address at an affordable price which satisfactory quality level. |
| Achievement of Defect Free Deliveries | Achievement of defect free delivery is to reduce costs, increase productivity and increase usability. |

## APPENDIX-E

| Definition/explanation of SC performance indicators (Refer to Table 6.1) | |
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| **Performance indicator(s)** | **Definitions/Explanations** |
| Customer Service | The process of ensuring customer satisfaction with a product or service. Often, customer service takes place while performing a transaction for the customer, such as making a sale or returning an item. Customer service can take the form of an in-person interaction, a phone call, self-service systems, or by other means. [Source: www.investopedia.com] |
| Order Fill Rate | Order fill rate, also known as demand satisfaction rate is a percentage of consumption orders satisfied from stock available at a moment. It is a measure of an inventory's ability to meet customer demand. One needs to keep this order rate as high as possible to avoid delay in production of final product. [Source: www.mbaskool.com] |
| Line Item Fill Rate | It is a measure of the ratio of the actual orders filled in terms of parallel arrangements or lines. [Source: www.mbaskool.com] |
| Quantity Fill Rate | It is the rate at which an order is met as compared to the total order or demand. This can be expressed as a simple ratio of the items/goods arrived to that of the total ordered. [Source: www.mbaskool.com] |
| Backorders/Stock outs | A term used in product manufacturing or distribution to describe an inventory shortfall arising from unexpected demand, ineffective inventory management, production delays or replenishment disruptions. Companies that experience stock outs may experience loss of future business due to customer dissatisfaction. [Source: www.investorwords.com] |
| Customer Satisfaction | Customer satisfaction refers to the extent to which customers are happy with the products and services provided by a company. Customer satisfaction levels can be measured using survey techniques and questionnaires. [Source: www.businesscasestudies.co.uk] |
| %Resolution of first customer call | It has been reported that for every 1% improvement in first call resolution, one can get 1% improvement in customer satisfaction. Additionally, if a customer's inquiry or problem is resolved in the first call, only 3% of those customers may be at risk of switching to a competitor. [Source: www.nearshoreamericas.com] |
| Customer Returns | Customer returns generally include the following: i) Products actually purchased and then returned for various reasons by customers. ii) Most stores include in-store damages with customer returns. Many stores include clearance products with customer returns. Customer returns can include any product category consisting of both consumer hard lines and/or soft lines. [Source: www.eventsale.com] |
| Order Track and Trace Performance | Monitoring a collection a stocks, whether held in a real or imaginary portfolio, for the purposes of learning how the prices move or profiting from those movements. Usually done with software or via the internet. [Source: www.investorwords.com] |

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| Customer Disputes | Consumer dispute means a dispute where the person against whom a complaint has been made, denies or disputes the allegations contained in the complaint.<br>[Source: www.lawzonline.com] |
| Order Entry Accuracy | Process of entering order information to a fulfillment system. The most important objectives of order entry are speed and accuracy so that customers can receive what they have ordered as quickly as possible and marketers can determine which promotions are working best. In addition to product and customer information, order entry must also capture a key code and payment type (cash, credit, credit card).<br>[Source: www.answers.com] |
| Order Entry Times | This is a process of recording an order into the company's data entry system. Once an order is entered, the company can view information about this order and make necessary changes for the entry.<br>[Source: www.businessdictionary.com] |
| Purchasing Management | An individual in a company who has the responsibility of purchasing the items required by the company. The purchasing manager is typically in charge of purchasing whatever the company needs, from regular office supplies, to the materials that would be used to manufacture the company's products. In larger companies, the purchasing manager's role will sometimes be more supervisory, with other employees in charge of placing the orders.<br>[Source: www.businessdictionary.com] |
| Material Inventories | A compilation of the supplies that are needed to produce or manufacture a product or service.<br>[Source: www.businessdictionary.com] |
| Supplier Delivery Performance | Fulfillment of a customers demand to the wish date. |
| Material/Component Quality | Pre-established measure of the quality of a material, expressed in physical units.<br>[Source: www.businessdictionary.com] |
| Material Stock Outs | A situation in which the demand or requirement for an item cannot be fulfilled from the current inventory.<br>[Source: www.businessdictionary.com] |
| Unit Purchase Costs | The cost incurred by a company to produce, store and sell one unit of a particular product. Unit costs include all fixed costs (i.e. plant and equipment) and all variable costs (labor, materials, etc.) involved in production.<br>[Source: www.investopedia.com] |
| Material Acquisition Costs | The cost that a company recognizes on its books for material after adjusting for discounts, incentives, closing costs and other necessary expenditures, but before sales taxes.<br>[Source: www.investopedia.com] |
| Expediting Activities | The process of expediting means to chase up purchase orders to ensure the timeliest delivery possible.<br>[Source: www.procurementcourse.com] |
| Administration/Financial Management | Finance is the life blood of very business. As personnel and materials which are necessary for the functioning of any office, industry, enterprise can be made available through money. Hence, finance plays an important role in the business.<br>[Source: www.iamsam.hubpages.com] |
| Cash Flow | A revenue or expense stream that changes a cash account over a given period. Cash inflows usually arise from one of three activities - financing, operations or investing - although this also occurs as a result of donations or gifts in the case |

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| | of personal finance. Cash outflows result from expenses or investments. This holds true for both business and personal finance.<br>[Source: www.investopedia.com] |
| Revenue | The income generated from sale of goods or services, or any other use of capital or assets, associated with the main operations of an organization before any costs or expenses are deducted. Revenue is shown usually as the top item in an income (profit and loss) statement from which all charges, costs, and expenses are subtracted to arrive at net income.<br>[Source: www.businessdictionary.com] |
| Return on Capital Employed (ROCE) | A financial ratio that measures a company's profitability and the efficiency with which its capital is employed. Return on Capital Employed (ROCE) is calculated as: (ROCE = Earnings Before Interest and Tax (EBIT) / Capital Employed). [Source: www.investopedia.com] |
| Cash-to-Cash Cycle | A financial ratio showing for how long a company has to finance its own stock/inventory. It measures the number of days between the initial cash outflow (when the company pays its suppliers) to the time it receives cash from its customers and is calculated as: (stock days + debtor days - creditor days).<br>[Source: www.finance-glossary.com] |
| Return on Investment | The overall profit (or loss) on an investment, including both dividends and price appreciation, expressed as a percentage of the total invested.<br>[Source: www.finance-glossary.com] |
| Revenue Per Employee | An important ratio that looks at a company's sales in relation to the number of employees they have.<br>[Source: www.investopedia.com] |
| Invoice Errors | A nonnegotiable commercial instrument issued by a seller to a buyer. It identifies both the trading parties and lists, describes, and quantifies the items sold, shows the date of shipment and mode of transport, prices and discounts (if any), and delivery and payment terms.<br>[Source: www.businessdictionary.com] |
| Return on Assets (ROA) | An indicator of how profitable a company is relative to its total assets. ROA gives an idea as to how efficient management is at using its assets to generate earnings. Calculated by dividing a company's annual earnings by its total assets, ROA is displayed as a percentage. |
| Process, Cross Functional Measures | It is related to the organizational plan for human resources, marketing, research and development and other functional areas. The functional strategy of a company is customized to a specific industry and is used to back up other corporate and business strategies. [Source: www.businessdictionary.com] |
| Forecast Accuracy | The accuracy of forecast is the degree of closeness of the statement of quantity to that quantity's actual (true) value. The actual value usually cannot be measured at the time the forecast is made because the statement concerns the future. For most of the businesses, more accurate forecasts increase their effectiveness to serve the demand while lowering overall operational costs.<br>[Source: www.lokad.com] |
| Percent Perfect Orders | Perfect order fulfillment as a discrete measurement defined as the percentage of orders delivered to the right place, with the right product, at the right time, in the right condition, in the right package, in the right quantity, with the right |

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| | documentation, to the right customer, with the correct invoice. Failure to meet any of these conditions results in a less than perfect order. [Source: www.inboundlogistics.com] |
| New Product-Time-To-Market | The length of time it takes to get a product from idea to marketplace. Process of developing a new product or service for the market. New product development is essential to any business that must keep up with market trends and changes. [Source: www.investorwords.com] |
| New Product-Time-To-First-Make | Process of developing a new product or service for the market. This type of development is considered the preliminary step in product or service development and involves a number of steps that must be completed before the product can be introduced to the market. New product development may be done to develop an item to compete with a particular product/service or may be done to improve an already established product. New product development is essential to any business that must keep up with market trends and changes. [Source: www.businessdictionary.com] |
| Planning Process Cycle Time | The development of goals, strategies, task lists and schedules required to achieve the objectives of a business. The planning process is a fundamental function of management and should result in the best possible degree of satisfaction given the resources available. The time that elapses from the beginning to the end of a process. [Source: www.businessdictionary.com] |
| Schedule Changes | Customer-directed alteration that requires a modification in a project's cost or schedule. [Source: www.businessdictionary.com] |
| Manufacturing Management | Rationalizations and improvement of adapted and flexible production systems by management of an internal and external variety of the product ranges from the design phase to its expedition by the application of modern techniques. [Source: www.danobatgroup.com] |
| Product Quality | The group of features and characteristics of a saleable good which determine its desirability and which can be controlled by a manufacturer to meet certain basic requirements. Most businesses that produce goods for sale have a product quality or assurance department that monitors outgoing products for consumer acceptability. [Source: www.businessdictionary.com] |
| WIP Inventories | Work-in-process inventory is the inventory that is partially converted through the production process, but for which additional work must be completed before it can be transported out of the manufacturing area and recorded as finished goods inventory. [Source: www.accountingtools.com] |
| Adherence to Schedule | An automated or manual process of ensuring that the number of agents available to handle calls in an organization 'adheres' to the projected schedule of agents needed. [Source: www.pcmag.com] |
| Cost Per Unit Produced | The cost incurred by a company to produce, store and sell one unit of a particular product. Unit costs include all fixed costs (i.e. plant and equipment) and all variable costs (labor, materials, etc.) involved in production. [Source: www.investopedia.com] |
| Setups/Changeovers | One-time portion of a production cycle in which a specific machine, work center, or assembly line is 'made ready' to |

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| | switch from production of the last good piece of the last lot to the first good piece of the new lot. [Source: www.businessdictionary.com] |
| Setup/Changeover Costs | Expenses incurred in setting up a machine, work center, or assembly line, to switch from one production job to the next. [Source: www.businessdictionary.com] |
| Unplanned Stockroom Issues | Having no particular purpose, organization, or structure of a storage place for supplies or goods used in a business. [Source: www.merriam-webster.com] |
| Bill-of-Materials Accuracy | A Bill of Materials Accuracy is a detailed list of all parts and subassemblies that are required to build a specific product, including the quantity necessary for each unit produced. [Source: www.operationstech.about.com] |
| Routing Accuracy | When specified activities conform to administrative specifications, and specified resource consumptions (both man and machine) are detailed according to administrative specifications and are within a given percentage of actual requirements. [Source: www.lindnerlogistics.com] |
| Plant Space Utilization | Extent or level to which the productive capacity of a plant, firm, is being used in generation of goods and services. [Source: www.businessdictionary.com] |
| Line Breakdowns | A price movement through an identified level of support, which is usually followed by heavy volume and sharp declines. Technical traders will short sell the underlying asset when the price of the security breaks below a support level because it is a clear indication that the bears are in control and that additional selling pressure is likely to follow. [Source: www.investopedia.com] |
| Warranty Costs | If a product or service becomes damaged and is returned to the company, the company will expense the cost of replacing the item or issuing a refund. [Source: www.businessdictionary.com] |
| Source-to-make-Cycle Time | Time required for raw material to finished product. |
| Percent Scrap/Rework | Percentage of failed assemblies or material that cannot be repaired or restored, and is therefore condemned and discarded. [Source: www.businessdictionary.com] |
| Material Usage Variance | Material Usage Variance is the measure of difference between the actual quantities of material utilized during a period and the standard consumption of material for the level of output achieved. [Source: accounting-simplified.com] |
| Overtime Usage | Overtime can improve the organization's competitive position in the local labor market because so many employees like the extra income. [Source: www.industryweek.com] |
| Production Cycle Time | The production cycle represents part of the production time, excluding the period during which the objects of labor are in production reserves. [Source: encyclopedia2.thefreedictionary.com] |
| Manufacturing Productivity | A measure of the efficiency of a person, machine, factory, system, etc., in converting inputs into useful outputs. |

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| | Productivity is computed by dividing average output per period by the total costs incurred or resources (capital, energy, material, personnel) consumed in that period. Productivity is a critical determinant of cost efficiency.<br>[Source: www.businessdictionary.com] |
| Master Schedule Stability | The most complete schedule for a project, it covers not only the construction portions, but also items that are not strictly construction-related, such as financing deadlines and community board reviews. The master schedule includes all the details of the project, but can be presented in a summary or executive-level format, with the ability to 'drill down' into specific parts to get more detailed information, as needed.<br>[Source: www.dictionaryofconstruction.com] |
| Marketing Management | The application, tracking and review of a company are marketing resources and activities. The scope of a business' marketing management depends on the size of the business and the industry in which the business operates. Effective marketing management will use a company's resources to increase its customer base, improve customer opinions of the company's products and services, and increase the company's perceived value.<br>[Source: www.businessdictionary.com] |
| Market Share | The percentage of an industry or market's total sales that is earned by a particular company over a specified time period. Market share is calculated by taking the company's sales over the period and dividing it by the total sales of the industry over the same period. This metric is used to give a general idea of the size of a company to its market and its competitors.<br>[Source: www.investopedia.com] |
| Percent of Sales from New Products | When a new product intrudes on the existing market for the older product, rather than expanding the company's market base. Rather than appealing to a new segment of the market and increasing market share, the new product appeals to the company's current market, resulting in reduced sales and market share for the existing product.<br>[Source: www.investopedia.com] |
| Time-To-Market | Length of time taken in product development process from product idea to the finished product. It is a critical component of time based competition.<br>[Source: www.businessdictionary.com] |
| Repeat versus New Customer Sales | A situation that arises when a customer returns again and again to purchase a good or service from a business. Offering repeat business is the hallmark of a steady customer that is usually highly valued by businesses that they patronize since they typically require minimal additional marketing efforts to retain. A new marketing technique helps to create new customer sales.<br>[Source: www.businessdictionary.com] |
| Extended Enterprise Measures | Wider organization' representing all associated entities customers, employees, suppliers, distributors, etc. who directly or indirectly, formally or informally, collaborate in the design, development, production, and delivery of a product to the end user.<br>[Source: www.businessdictionary.com] |
| Total Landed Cost | The total cost of goods that have been shipped to a location, including the price of the goods, any fees for shipping, and any port fees, taxes, or customs duties that may apply. The landed cost of shipped goods will generally be factored into |

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| | the price at which the goods will be sold.<br>[Source: www.investorwords.com] |
| Point of Consumption Product Availability | The process in which the substance of a thing is completely destroyed, used up, or incorporated or transformed into something else. Consumption of goods and services is the amount of them used in a particular time period.<br>[Source: www.businessdictionary.com] |
| Total Supply Chain Inventory | Managing a supply chain is very different from managing one site. The inventory stockpiles at the various sites, including both incoming materials and finished products, have complex interrelationships. Efficient and effective management of inventory throughout the supply chain significantly improves the ultimate service provided to the customer.<br>[Source: www.sloanreview.mit.edu] |
| Retail Shelf Display | Shelf-talkers, hanging signs (mobiles), window displays, etc., aimed at influencing a purchase at a retail outlet.<br>[Source: www.businessdictionary.com] |
| Channel Inventories | The amount of inventory that is in the process of being made available for delivery to the end customer.<br>[Source: www.yourdictionary.com] |
| EDI Transactions | Electronic Data Interchange (EDI) is the electronic interchange of business information using a standardized format. In other words, EDI is a process which allows one company to send information to another company electronically rather than with paper. Business entities which conduct business electronically are called trading partners.<br>[Source: www.uprr.com] |
| Percent of Demand/Supply on VMI/CRP | A situation that occurs when the price elasticity of demand is equal to negative one (-1). For a business, when a product exhibits unitary demand this means that a given percent shift in the price of the product results in an equal but opposite percent change in the amount of product demanded. Hence, a one percent change in price yields a one percent decline in the amount of product demanded.<br>Inventory replenishment arrangement whereby the supplier either monitors the customer's inventory with own employees or receives stock information from the customer. The vendor then refills the stock automatically, without the customer initiating purchase orders.<br>Quick but rough method of capacity planning in which the demand or load on each resource or work center is added up, without regard to setup time. CRP is used usually to determine if a proposed master production schedule (MPS) is practicable.<br>[Source: www.businessdictionary.com] |
| Percent of Suppliers Getting Shared Forecast | Forecast sharing in a supply chain using linear price contracts often leads to inefficiencies as the buyer has an incentive to inflate demand forecasts to ensure sufficient supply.<br>[Source: www.faculty.haas.berkeley.edu] |
| Supplier Inventories | A means of optimizing supply chain performance in which the manufacturer is responsible for maintaining the distributor's inventory levels. The manufacturer has access to the distributor's inventory data and is responsible for generating purchase orders.<br>[Source: www.vendormanagedinventory.com] |
| Internet Activity to Suppliers/Customers | Broad term covering all commercial activity on the internet, including auctioning, placing orders, making payments, |

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| | transferring funds, and collaborating with trading partners. Internet commerce is not a synonym for electronic commerce (e-commerce) but one of its subsets.<br>[Source: www.businessdictionary.com] |
| Percent Automated Tendering | An internet based process wherein the complete tendering process; from advertising to receiving and submitting tender-related information are done online. This enables firms to be more efficient as paper-based transactions are reduced or eliminated, facilitating for a more speedy exchange of information.<br>[Source: www.businessdictionary.com] |
| Logistics Performance | The key success factors for achieving logistics performance remain: alignment between group development strategy, warehousing and production capacity, forecasting and dimensioning of supplies and manufacturing capacities, efficient industrial logistic flows, but also adequate track and trace systems.<br>[Source: www.lifecycle-experience.altran.com] |
| Finished Goods Inventory Turns | A reflection of the amount of manufactured product in stock that is available for customer purchase. On an income statement, the finished goods inventory is considered an asset to the company.<br>[Source: www.businessdictionary.com] |
| Finished Goods Inventory Days of Supply | Total gross value of inventory at standard cost before reserves for excess and obsolescence. Only includes inventory on company books, future liabilities should not be included.<br>[Source: www.wiki.scn.sap.com] |
| On-Time Delivery | A metric used to assess the ability of a business to fulfill shipping orders or other transactions within the period of time promised to a client or customer. Time delivery is generally expressed as the percentage of transactions that are achieved within the specified timeframe, and is often an area of focus for process improvement initiatives.<br>[Source: www.businessdictionary.com] |
| Lines Picked/Hour | A time of day in which large numbers of transaction per hour between supplier and customer. |
| Damaged Shipments | Damage affecting the contents of a sealed (and apparently undamaged) shipping container. Concealed damage claims are hard to settle because neither the carrier not the shipper takes the blame.<br>[Source: www.businessdictionary.com] |
| Inventory Accuracy | The notion of inventory accuracy refers to all the discrepancies that exist between electronic records that represent the inventory and the physical state of the inventory. One of the most common forms of inventory inaccuracy is phantom inventory. Such discrepancies can result in lower service levels, along with broader accounting issues and financial losses.<br>[Source: www.lokad.com] |
| Pick Accuracy | The degree of agreement between the quantity and type of stock-keeping units on an order form, picking document, and those actually present in a given load. Poor shipping accuracy is linked to low levels of customer satisfaction and increased costs for correcting errors.<br>[Source: www.businessdictionary.com] |
| Logistics Cost | Logistics costs influence the whole value chain because they occur many times in production function.<br>[Source: www.kmpfl.devgateway.org] |

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| Shipment Accuracy | The degree of agreement between the quantity and type of stock-keeping units (SKUs) on an order form, picking document, or BOL and those actually present in a given load. Poor shipping accuracy is linked to low levels of customer satisfaction and increased costs for correcting errors. Barcode labeling and scanning systems are often implemented to increase accuracy.<br>[Source: www.businessdictionary.com] |
| On-Time Shipment | Period taken by a shipment to reach its intended destination. Together with order time, it constitutes the elapsed time between a requisition and the item's availability.<br>[Source: www.businessdictionary.com] |
| Delivery Times | In general, time when actual delivery takes place. Also, alternative term for delivery period.<br>[Source: www.businessdictionary.com] |
| Warehouse Space Utilization | It's the warehouse managers' responsibility to make sure that sufficient space is available for all goods that are to be stored in the warehouses that they control. Proper utilization of warehouse space leads to increase efficiency of organization.<br>[Source: www.blogs.msdn.com] |
| End-of-Life Inventory | Inventory on hand that will satisfy future demand for products that are no longer in production at the entity.<br>[Source: www.careersinsupplychain.ca] |
| Obsolete Inventory | A company's inventory that has no additional usage or sales capability because it has reached the end of its product life cycle. In many cases, this type of inventory may cause losses on a company's balance sheet and overall profitability.<br>[Source: www.businessdictionary.com] |
| Inventory Shrinkage | Material or goods lost through deterioration, obsolescence, pilferage, theft, and/or waste.<br>[Source: www.businessdictionary.com] |
| Cost of Carrying/Holding Inventory | This is the cost a business incurs over a certain period of time, to hold and store its inventory. Businesses use this figure to help them determine how much profit can be made on current inventory. It also helps them find out if there is a need to produce more or less, in order to keep up with expenses or maintain the same income stream.<br>Carrying cost of inventory is often described as a percentage of the inventory value. This percentage could include taxes, employee costs, depreciation, insurance, cost to keep items in storage, opportunity cost, cost of insuring and replacing items, and cost of capital that help produce income for a business.<br>[Source: http://www.investopedia.com] |
| Documentation Accuracy | Accurate preparation of a set of commercial and financial documents that record or support a business transaction.<br>[Source: www.businessdictionary.com] |
| Transportation Cost | The expenses involved in moving products or assets to a different place, which is often passed on to consumers. For example, a business would generally incur a transportation cost if it needs to bring its products to retailers in order to have them offered for sale to consumers.<br>[Source:www.businessdictionary.com] |
| Warehousing Costs | The costs involved in storing goods in a warehouse, performance of administrative and physical functions associated with storage of goods and materials. These functions include receipt, identification, inspection, verification, putting away, |

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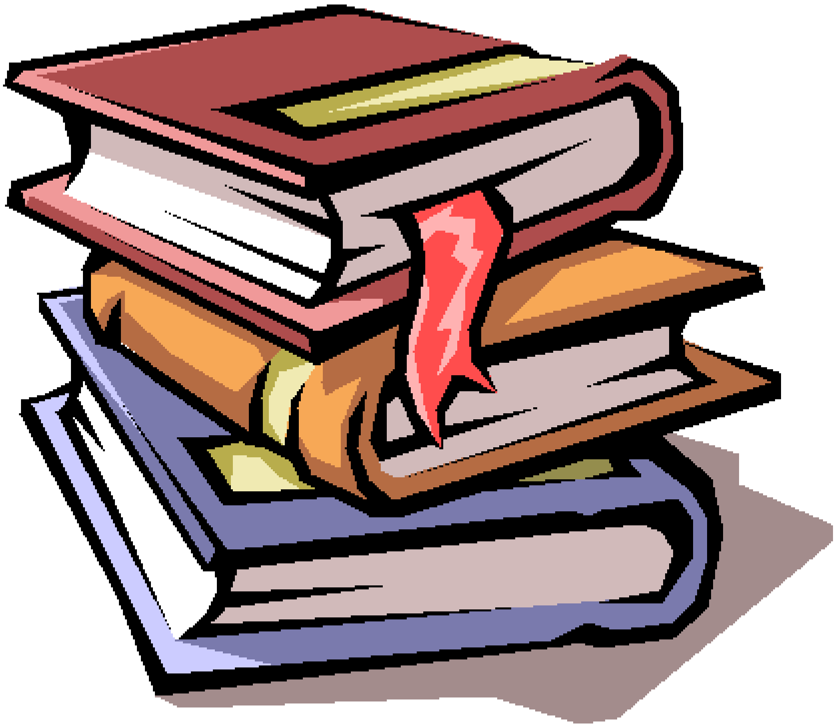
| | retrieval for issue, etc. [Source:www.businessdictionary.com] |
| Container Utilization | The Container Utilization administrative view returns information about space containers and utilization rates. [Source: www.publib.boulder.ibm.com] |
| Truck Cube Utilization | Loading a truck or other transportation vehicle with merchandise in order to fill as much of the horizontal and vertical space as possible. [Source:www.termwiki.com] |
| In-Transit Inventories | En-route goods or materials which are in the ownership of the firm but in the possession of the carrier. [Source:www.businessdictionary.com] |
| Premium Freight Charges | The cost incurred in moving goods. It includes packing, palletizing, documentation and loading unloading charges, carriage costs, and marine insurance costs. [Source:www.businessdictionary.com] |
| Warehouse Receipts | Receipt of goods or materials left for safekeeping in a warehouse. It is a non-negotiable instrument if it permits delivery only to a named entity; a negotiable instrument when bearer or made out to the order of the holder. [Source: www.businessdictionary.com] |



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# List of Publications

**Santosh Kumar Sahu**, Saurav Datta, Saroj Kumar Patel, Siba Sankar Mahapatra, (2013) *Supply Chain Performance Appraisement, Benchmarking and Decision-Making: Empirical Study using Grey Theory and Grey-MOORA*, **International Journal of Process Management and Benchmarking**, 3(3): 233-289, Inderscience Publishers, Switzerland.

**Santosh Kumar Sahu**, Saurav Datta, Saroj Kumar Patel, Siba Sankar Mahapatra, *Supply Chain Performance Appraisement Platform: Exploration of Interval-Valued Fuzzy Sets Theory*, **World Congress on Frontiers of Mechanical, Aeronautical and Automobile Engineering (WCFMAAE-2013)**, organized by Krishi Sanskriti on 2nd – 3rd February 2013, at Indian Institute of Technology, Hauzkhas, New Delhi-110016.

**Santosh Kumar Sahu**, Saurav Datta, Saroj Kumar Patel, Siba Sankar Mahapatra, *Supply Chain performance appraisement Platform in Fuzzy Context*, International Congress on **Innovative Trends in Information Technologies and Computing Sciences for Competitive World Order (ITITCSCWO – 2013)**, organized by Krishi Sanskriti, during 2nd-3rd March 2013 at Jawaharlal Nehru University, New Delhi-110067.

**Santosh Kumar Sahu**, Saurav Datta, Saroj Kumar Patel, Siba Sankar Mahapatra, *Decision-making scenario towards supply chain performance Assessment in Fuzzy Context*, **International Conference on Advances in Mechanical, Automobile and Aerospace Engineering (AMAAE-2013)**, organized by Krishi Sanskriti, during 21st to 22nd September 2013, held at Jawaharlal Nehru University, New Delhi-110067.

**Santosh Kumar Sahu**, Saurav Datta, Saroj Kumar Patel, and Siba Sankar Mahapatra, *Industrial Supply Chain Performance Benchmarking using Fuzzy Grey Relation Method*, **GLOBAL SUMMIT on Management of Business, Economy, Marketing and Services- New Approaches (MBEMSNA-2013)**, organized by Krishi Sanskriti during 9th-10th November, 2013 at Jawaharlal Nehru University, New Delhi-110067.

## Papers under Review

**Santosh Kumar Sahu**, Saurav Datta, Siba Sankar Mahapatra, Saroj Kumar Patel, *Fuzzy Embedded MULTIMOORA Method for appraisement, benchmarking and decision-making in supply chain: an empirical study*, **International Journal of Services and Operations Management**, Inderscience Publishers, Switzerland. **(Under Review)**

**Santosh Kumar Sahu**, Saurav Datta, Saroj Kumar Patel, Siba Sankar Mahapatra, *Development of Fuzzy Decision-Support Systems for Supply Chain Performance Appraisement: An Empirical Research*, **International Journal of Advanced Manufacturing Technology**, Springer-Verlag London Limited. **(Under Review)**

**Santosh Kumar Sahu**, Saurav Datta, Saroj Kumar Patel, Siba Sankar Mahapatra, *Decision-Support System for Supply Chain Performance Appraisement and Benchmarking: A Modified Version of Deng's Similarity Measure Approach*, **International Journal of Procurement Management**, Inderscience Publishers, Switzerland. **(Under Review)**

**Santosh Kumar Sahu**, Saurav Datta, Saroj Kumar Patel, Siba Sankar Mahapatra, *Appraisement and Benchmarking of Supply Chain Performance Extent: A Fuzzy Grey Relation Method*, **Proposal Accepted** for a Chapter for **Fuzzy Optimization and Multi-Criteria Decision Making in Digital Marketing** for release in the ***Advances in Marketing, Customer Relationship Management, and E-Services (AMCRMES)*** Book Series.

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## EDUCATIONAL BACKGROUND

| Degree | Examination Passed | Year of Passing | Institute | Board /University | Subject/Discipline /Specialization |
|---|---|---|---|---|---|
| X[10th] | H.S.C. Exam | 2000 | P.T.C. High School,Angul | B.S.E. Odisha | MIL(O), Eng, Sci, Social Sci, Math |
| Under Graduate Degree | Diploma | 2003 | K.I.M.E.T. Chhendipada, Angul | S.C.T.E. &V.T., Odisha | Mechanical Engineering |
| Graduate Degree | B. Tech. | 2007 | S.I.ET., Dhenkanal | B.P.U.T. Odisha | Mechanical Engineering |
| Post Graduate | M. Tech. (Res) | 2014 (Cont.) | N.I.T., Rourkela | N.I.T., Rourkela, Odisha | Production Engineering |

## PROFESSIONAL EXPERIENCES

| Organization | Period | | Designation |
|---|---|---|---|
| | From | To | |
| Kamalesh Construction Pvt. Ltd., Angul | May 2007 | July 2008 | Junior manager |
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